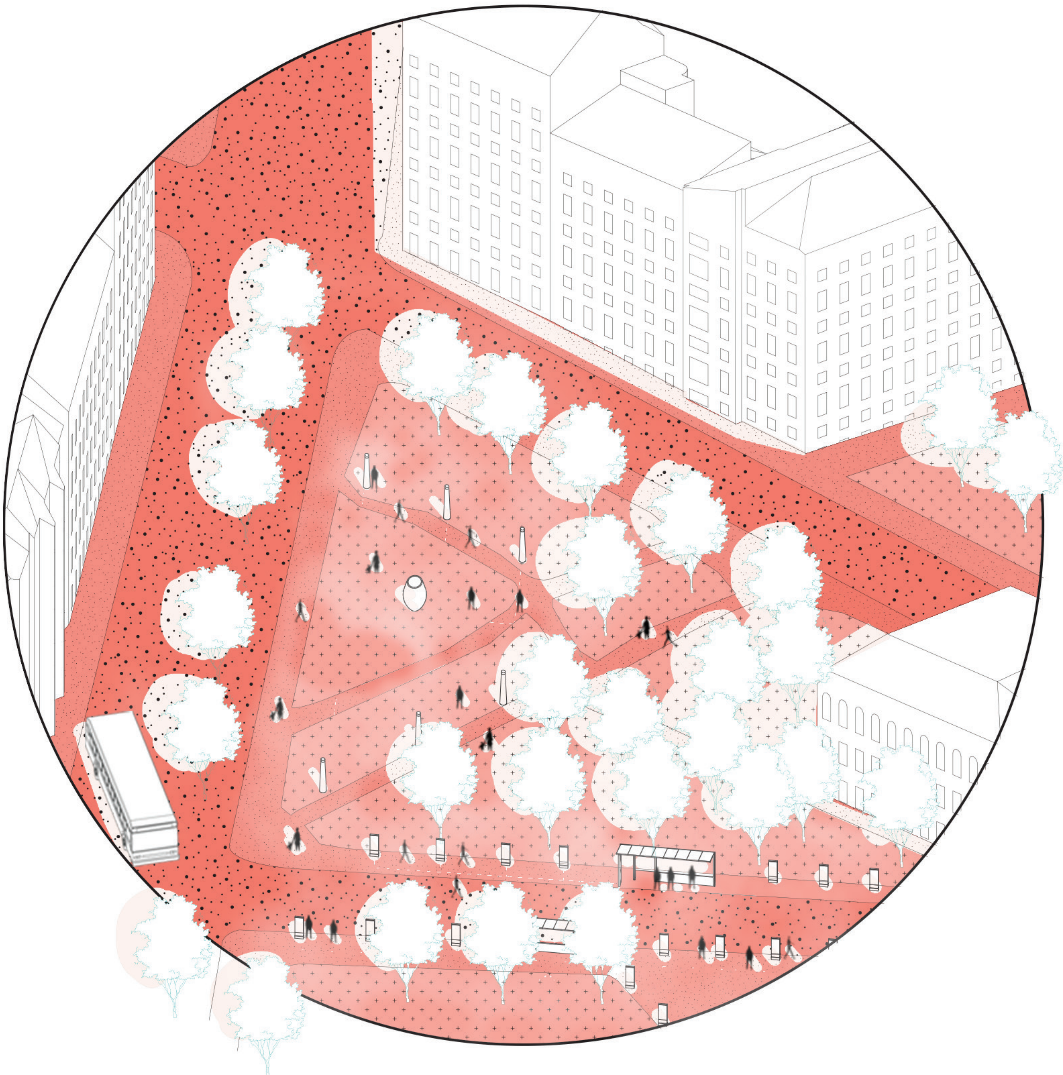
32°C Hellsinki

Outdoor Thermal Comfort Studies and Urban Mitigating Strategies Based on Helsinki Context



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ABSTRACT

Climate change has become an issue that must be considered in the future growth of cities. Europe's extreme climate has kept shattering the heat records in the past ten years and is projected to worsen. The mortality of the population due to heatwaves outclasses mortality caused by other extreme events. Elevated temperatures seriously threaten the health and well-being of the growing urban residents. Therefore, cities need to adopt actions to mitigate the worsening urban thermal environment in the forthcoming years.

In this thesis, a systematical and sustainable approach to mitigate Helsinki outdoor thermal comfort is proposed. Firstly, the thesis describes the thermal environment at different periods via the simulation of the central area. Simultaneously, the simulation also verifies that diverse ground covering materials have limited impacts on heat events' human thermal sensation. Notably, the shading created by constructions or trees has a significant effect on alleviating thermal stress.

Secondly, multiple combinations of urban cooling strategies are implemented according to different functional spaces. An interactive platform is designed to provide citizens with substantial services in summer. Governors can also selectively intervene in urban space through feedback from users. Moreover, towards the Helsinki Sustainable Development Goals, future urban scenarios have prospected.

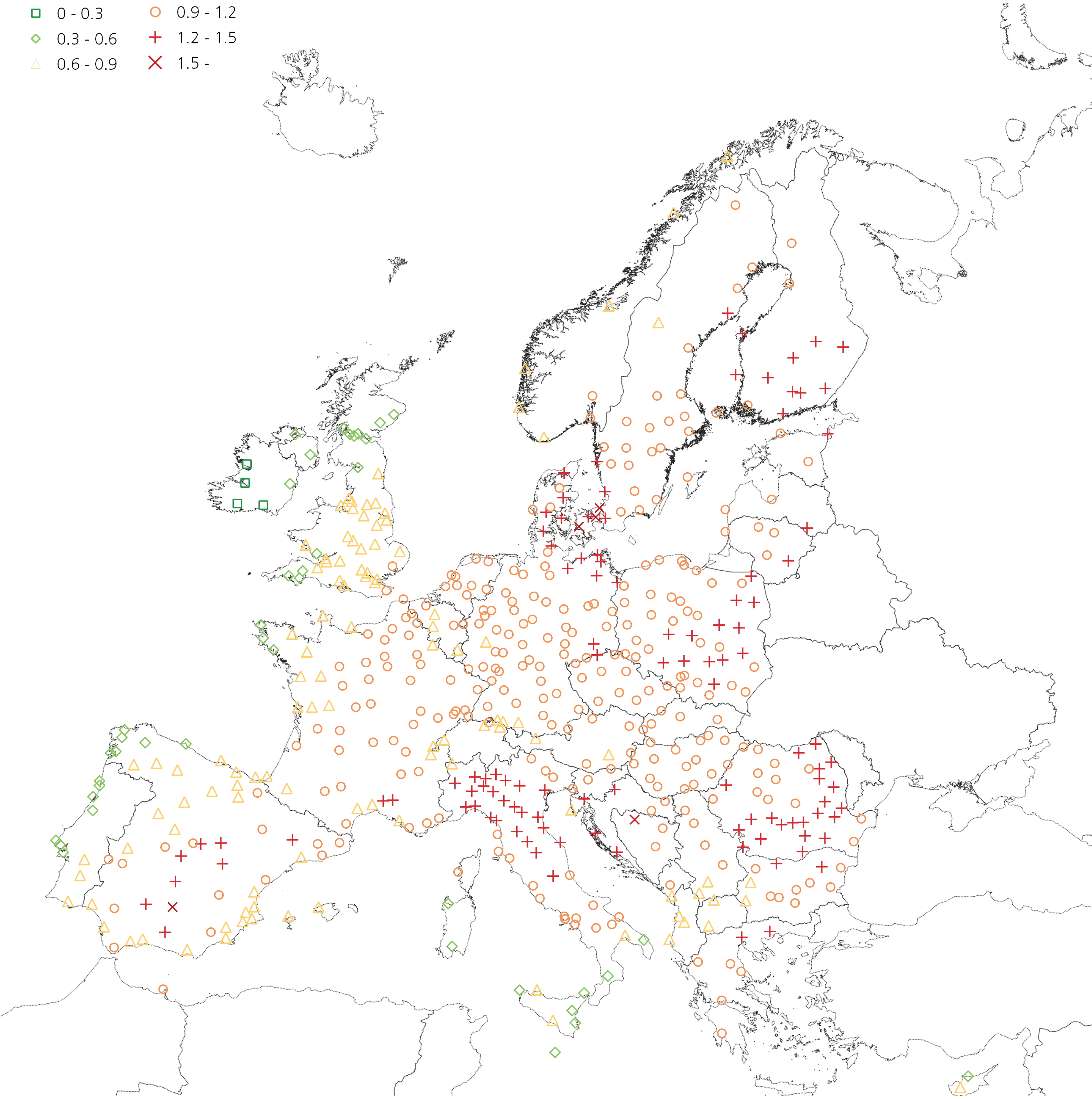
Keywords

Heat environment; Apparent temperature; Outdoor thermal comfort; Sustainability;
Urban strategy; Interaction; Well-being

ABBREVIATION LIST

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AT	Apparent Temperature
dPET	dynamic Physiological Equivalent Temperature
ET	Effective Temperature
HI	Heat Index
HSI	Heat Stress Index
MRT	Outdoor Mean Radiant Temperature
OUT_SET	Outdoor Standard Effective Temperature
PET	Physiological Equivalent Temperature
PMV	Predict Mean Vote
PST	Physiological Subjective Temperature
SET	Standard Effective Temperature
TS	Thermal Sensation
UHI	Urban Heat Island
UTCI	Universal Thermal Climate Index
WBGT	WetBulb Globe Temperature

CONTENTS



1.1 The increased temperature in Europe since last century (modified from EDJNet, 2018).

I INTRODUCTION

Chapter one introduces the thermal environment in four aspects: the current situation in Finland, the impacts on human health, the heatwaves in the urban context, and practical mitigation solutions at the design and planning level.

Heatwaves in Finland

The definition of heatwaves varies. P. Frich et al. (2002) defines a heatwave as at least 5 consecutive days during which the daily maximum temperature preponderates over 5 °C than the average maximum temperature. The normal temperature in the tropical climate can be considered as a heatwave in high latitudes if it is outside the regular climate pattern (P. Robinson, 2001).

The climate event corresponds with a peculiar atmospheric circulation in Europe, potentiated by augmenting greenhouse gas emissions. It means the specific circulation will lead to more severe, frequent, and prolonged heatwaves in Europe (G. Meehl, 2004).

The temperature in Finland has been rising since the last century. In Finland, heatwaves are defined as the days where the maximum temperature exceeds 25 °C (Finnish Meteorological Institute, 2019). According to the Finnish meteorological institute (2019), the heatwaves lasted 25 days in Helsinki in 2018. Heatwaves will become more frequent and persistent in the future. Even if the emissions get controlled (RCP=4.5), the maximum and average summer temperature in Helsinki in 2100 will both increase by 3 degrees compared to the present (A. Mäkelä, 2016).

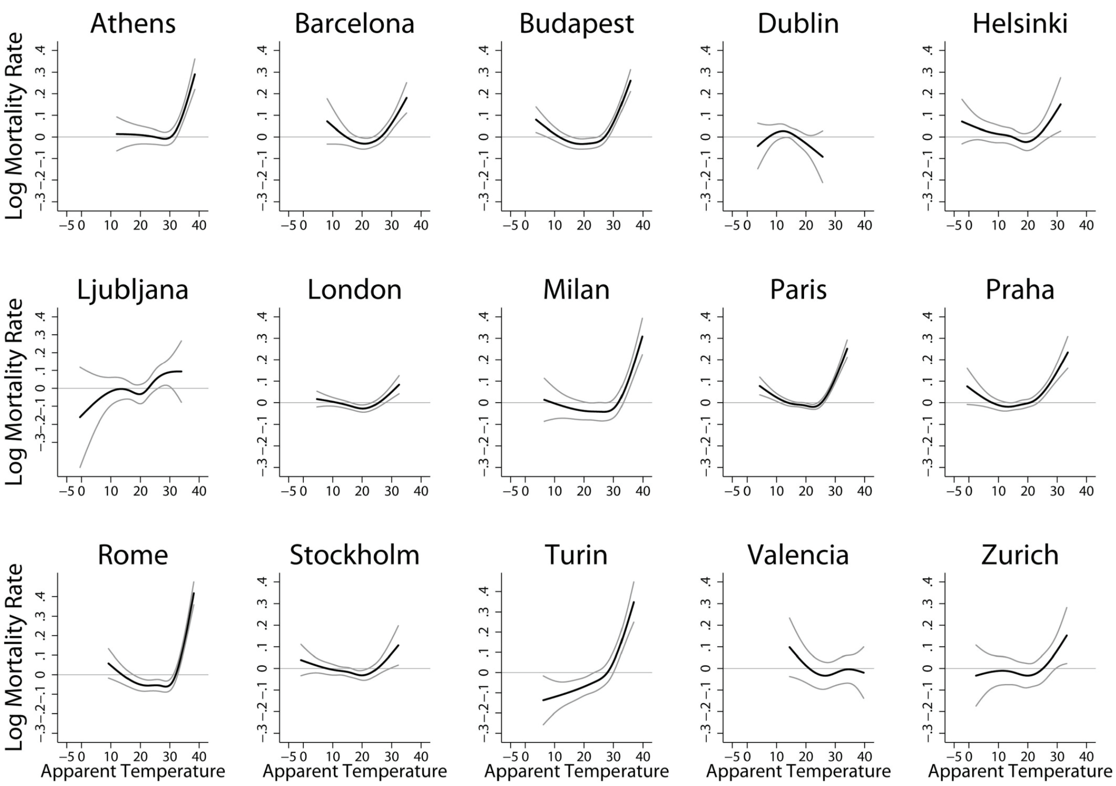
Periods of heatwave lead to increased direct or indirect impacts such as droughts, wildfires, and economic damages on urban and rural areas. Moreover, high temperatures can endanger people's lives and health, especially in urbanized areas where build-up materials and profiles aggrandize the radiant temperature and decrease air circulation.

Impacts on human health

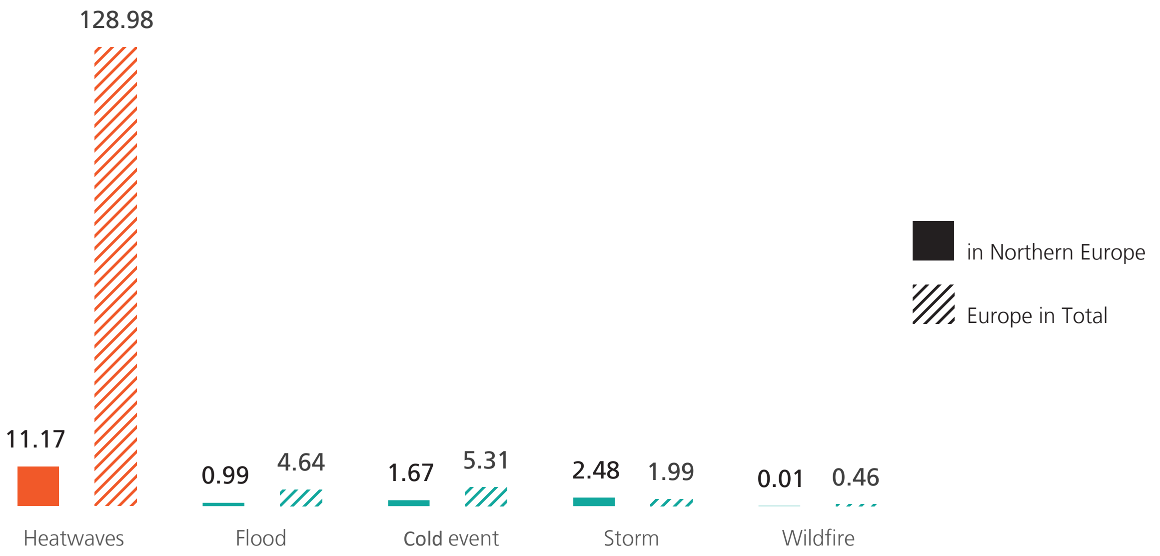
Depending on the severity, heatwaves can result in heat fatigue, heatstroke, and heat-related mortality. Such symptoms as exhaustion, faint, edema, skin rash, and muscle cramp are related to heat events. Exposing to the heat environment can worsen existing chronic illnesses, such as angiocardiopathy, respiratory diseases, and kidney issues (Analitis et al. 2014).

Heatwaves were the deadliest type of weather-related events, with 68% of 90325 additional deaths through the whole of Europe during the period 1980 to 2017 (EEA, 2019). Even in Nordic countries, mortality due to heatwaves outclasses mortality caused by other extreme weather events (EEA, 2017). Finnish Institute for Health and Welfare (2019) appraised 380 premature deaths resulting from the prolonged heatwave in 2018.

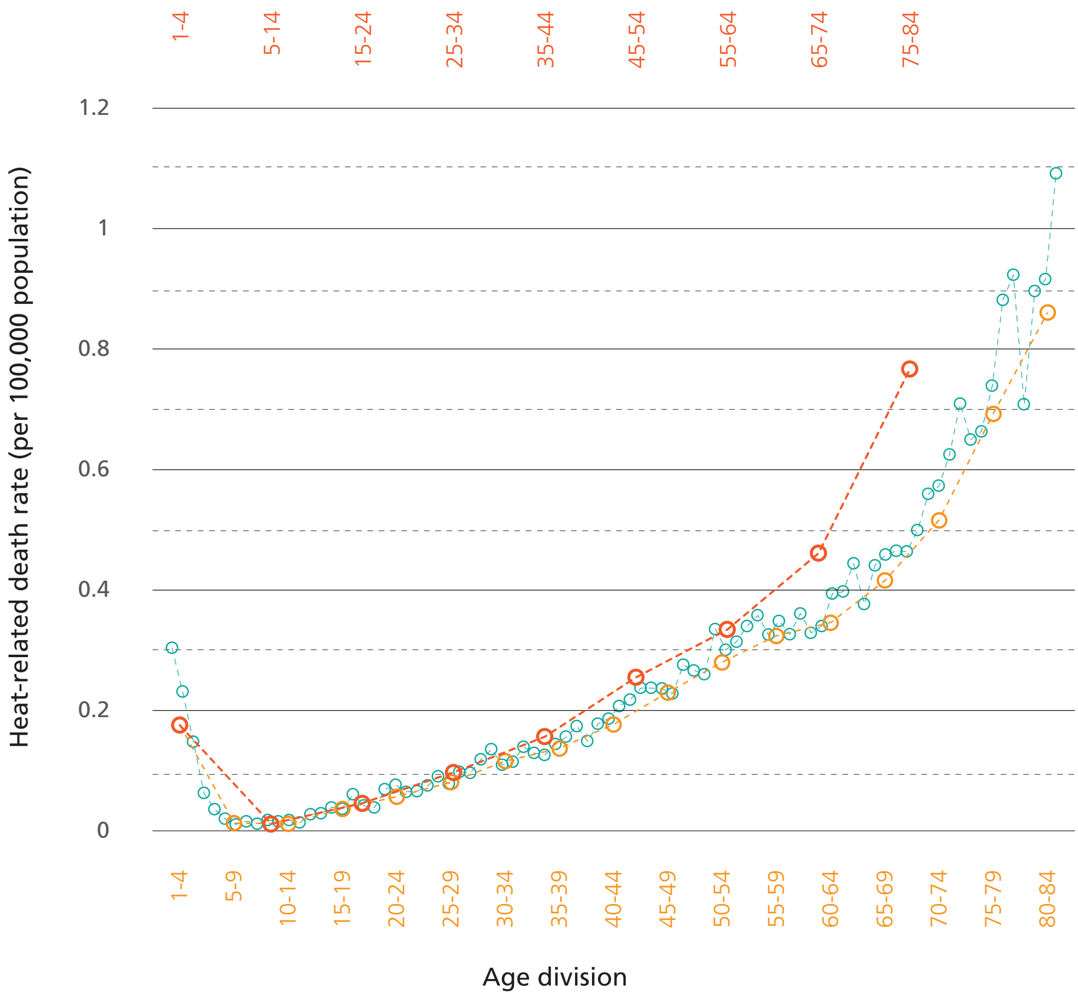
Furthermore, the elderly, children, patients with preexisting chronic illnesses, and groups in asthenic socioeconomic conditions are frequently listed as the most vulnerable communities amid the urban residents (Keramitsoglou et al., 2017; M. Smid et al., 2019).



1.2 The adjusted relationship between daily maximum apparent temperature and natural mortality in 15 European cities (B. Michela, 2008).



1.3 Number of people killed per million due to extreme climate events, for the period 1991-2015(modified form EEA,2017).

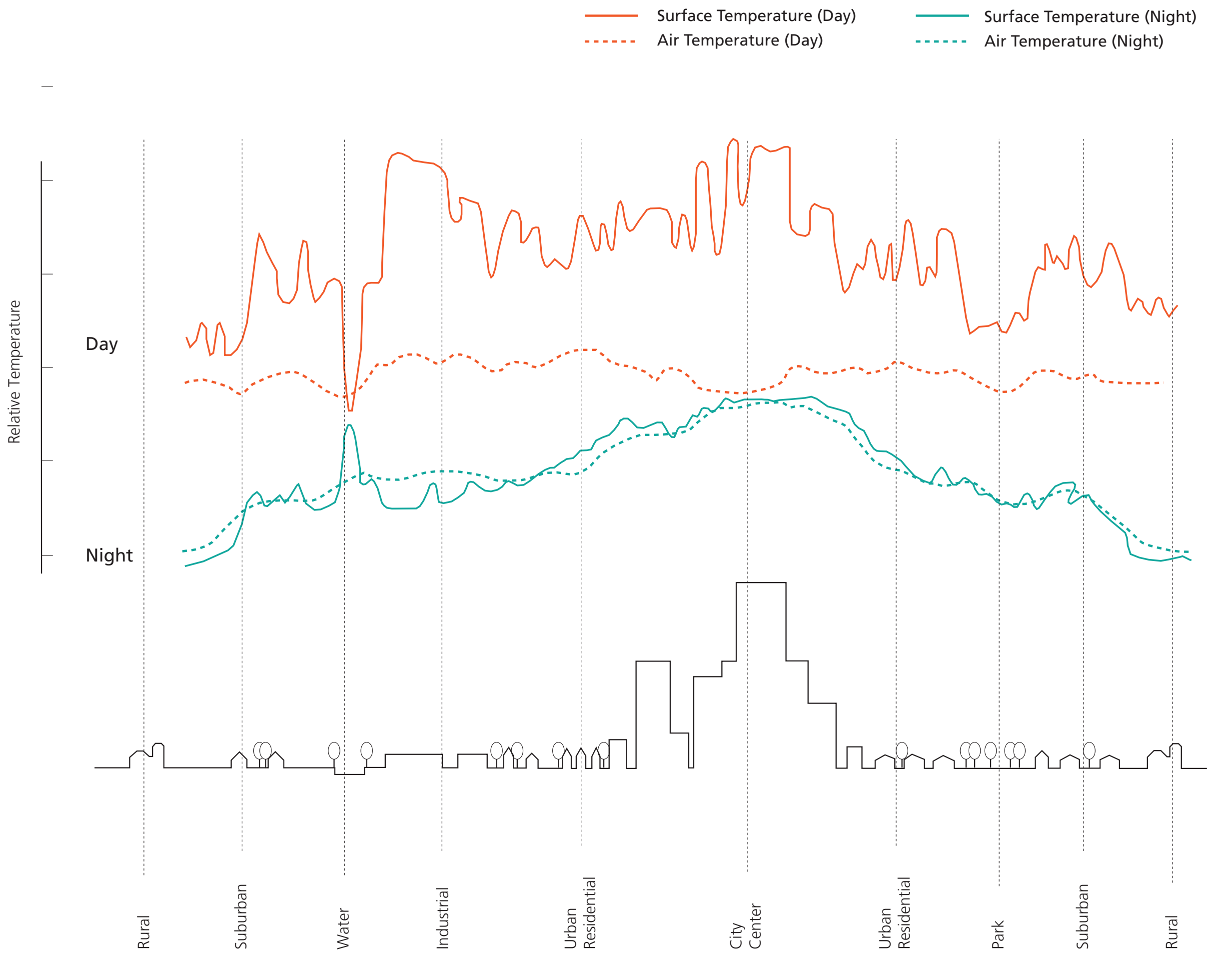


1.4 Average heat-related mortality rate in the USA from 1999-2018 (Data from Centers for Disease Control and Prevention, 2020).

Heatwaves in urban areas

The phenomenon of Urban Heat Island (UHI) exacerbates heatwaves and complicates the thermal environment in urban areas compared to the surrounding rural areas. Dense urban areas have higher mortality rates as a result of the UHI (Finnish Meteorological Institute, 2019).

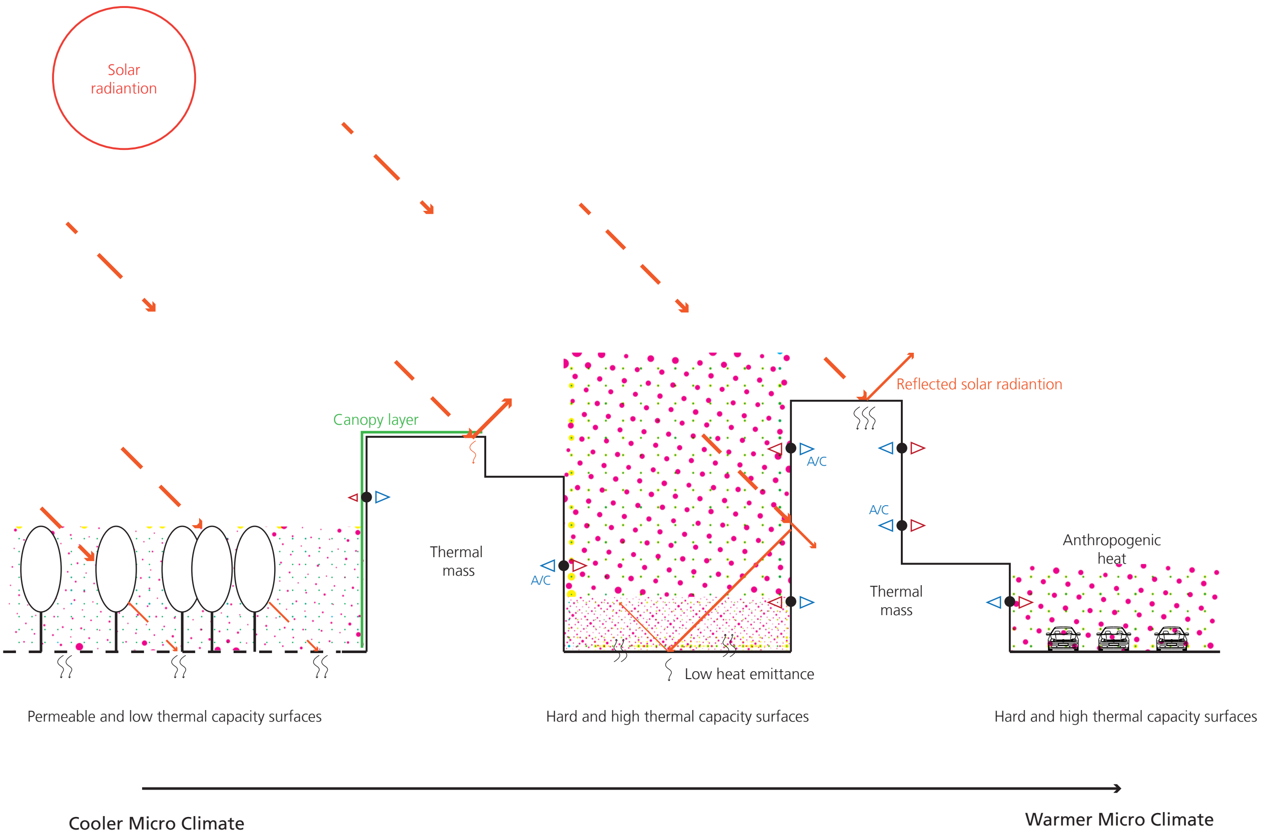
Besides anthropogenic heat produced by traffic and production, construction materials which absorb and obtain the solar radiation in the daytime release the heat to the surrounding during the night. The heat reduces air circulation and prevents the temperature from falling within the urban fabric. In the canyon-like configuration, constructions trap air and reduce wind speed. At the street level, part of the long-wave radiation is reflected from facades back to the pedestrians (L. Gartland, 2012).



1.5 Surface and atmospheric temperatures vary over different land-use areas (modified from U.S. Environmental Protection Agency, 2012).

Additionally, Impervious surfaces and dense structures lead to lower evapotranspiration in urban areas, which leads to the reduction of the relative humidity in the air. Humid air restraints the body from perspiring and evaporating to lower its apparent temperature. In other words, humid conditions amplify the risks of heat-related diseases when the heatwaves appear (E. Coffel, 2018).

Therefore, urban structure and landcover contribute to the urban heat island effect, which intensifies the heat events locally. It exacerbates the impacts of heatwaves on human health. Moreover, it increases energy consumptions for cooling down and costs for construction and infrastructure maintenance.



1.6 Urban structure, paving, and metabolism intensify the UHI effect in dense areas (modified from E. Sharifi; S. Lehmann, 2014).

Urban actions to mitigate the urban thermal environment

At present, numerous specific urban planning and design cases have been proved to alleviate UHI effectively. According to different action principles, the strategies can be divided into the following categories.

1. Improving surface albedo

Albedo, which means the ratio of the reflected solar radiation and the total received radiation by the object, determines the thermal behavior of ground surfaces (M. E. Hully, 2012). The covering materials with higher albedos contribute more to UHI.

Canoga Park in California has put a light grey coating on a dark asphalt road to test white paint's effectiveness. The result illustrates the paving materials can reach the 11 °C temperature difference on its surface (E. Rippe, 2017).

2. Intercepting solar radiation

The vegetation owns a similar albedo with brick and stone, whereas the interception of solar energy makes the vegetation play a prior role in mitigating the thermal environment. The surface covered with vertical green has a much lower temperature than covered by non-organic materials such as concrete and wood(T. Schröpfer, 2020).

Aiming to mitigate UHI by expanding the tree canopy coverage area, the City of Phoenix enabled the Cool Urban Space project in 2014. Compared with the treeless community, the community with tree canopy covered have a 4.3 °F temperature difference, and the grass-covered surfaces lead a 0.5 °F temperature reduction (A. Middel, 2014).

Material	Highly reflective roof	White paint	Grass	Brick and stone	Trees	Red or brown tile	Corrugated roof	Tar and gravel	Asphalt
Albedo	0.60-0.70	0.50-0.90	0.25-0.30	0.20-0.40	0.15-0.18	0.10-0.13	0.10-0.16	0.08-0.20	0.05-0.20

1.7 Typical albedos of urban surfaces (Modified from M. E. Hully, 2012).

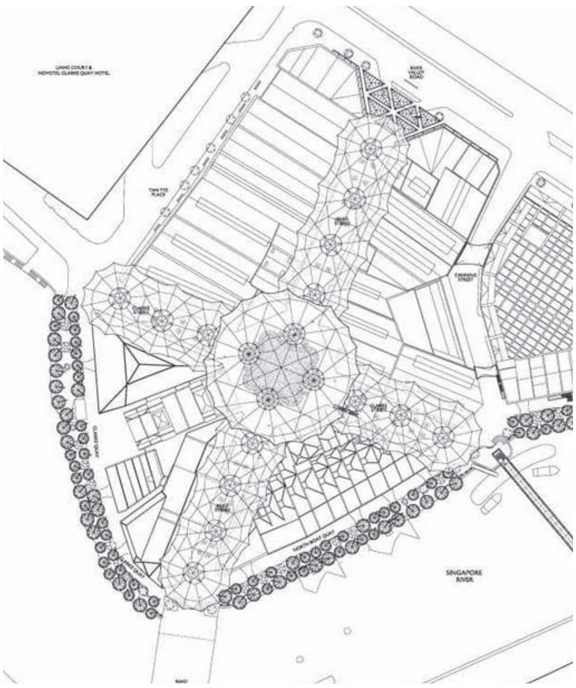
3. Enhancing air circulation

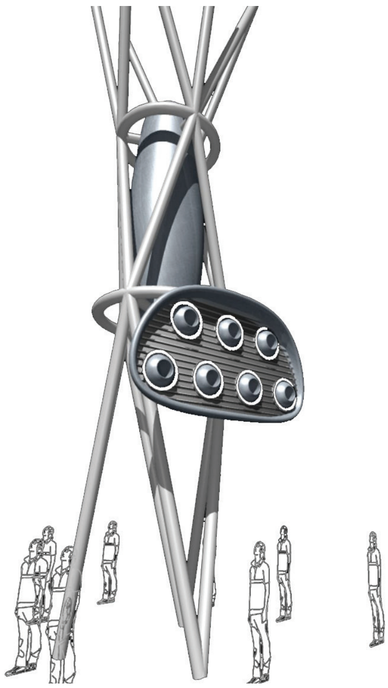
The accumulated heat in urban space cannot be convected in the urban context due to the increasing urban constructions. Therefore, many cities use wind channels to mitigate intensified UHI. Currently, cities such as Stuttgart, Tokyo, and Hongkong have formulated relevant guidelines to optimize urban ventilation.

4. Body scale cooling

Similar to air conditioners, many cooling devices have been developed for outdoor human body cooling. The principle of traditional cooling devices is to utilize heat transferring. In other words, the device spreads heat outside while refrigerating, which creates pressure on the surrounding environment. For instance, the outdoor cooling mechanism known as the Angels in Singapore provides an artificial breeze to pedestrians through the whale tail shape device (W.Alsop, 2006)

Another frequently used equipment is the outdoor misting system. Vents connected with water tanks or pipes spray liquid mist outside to cool the pedestrians physically. On the one hand, this method is environmentally friendly than heat transferring. On the other hand, it consumes a considerable deal of water in summer.



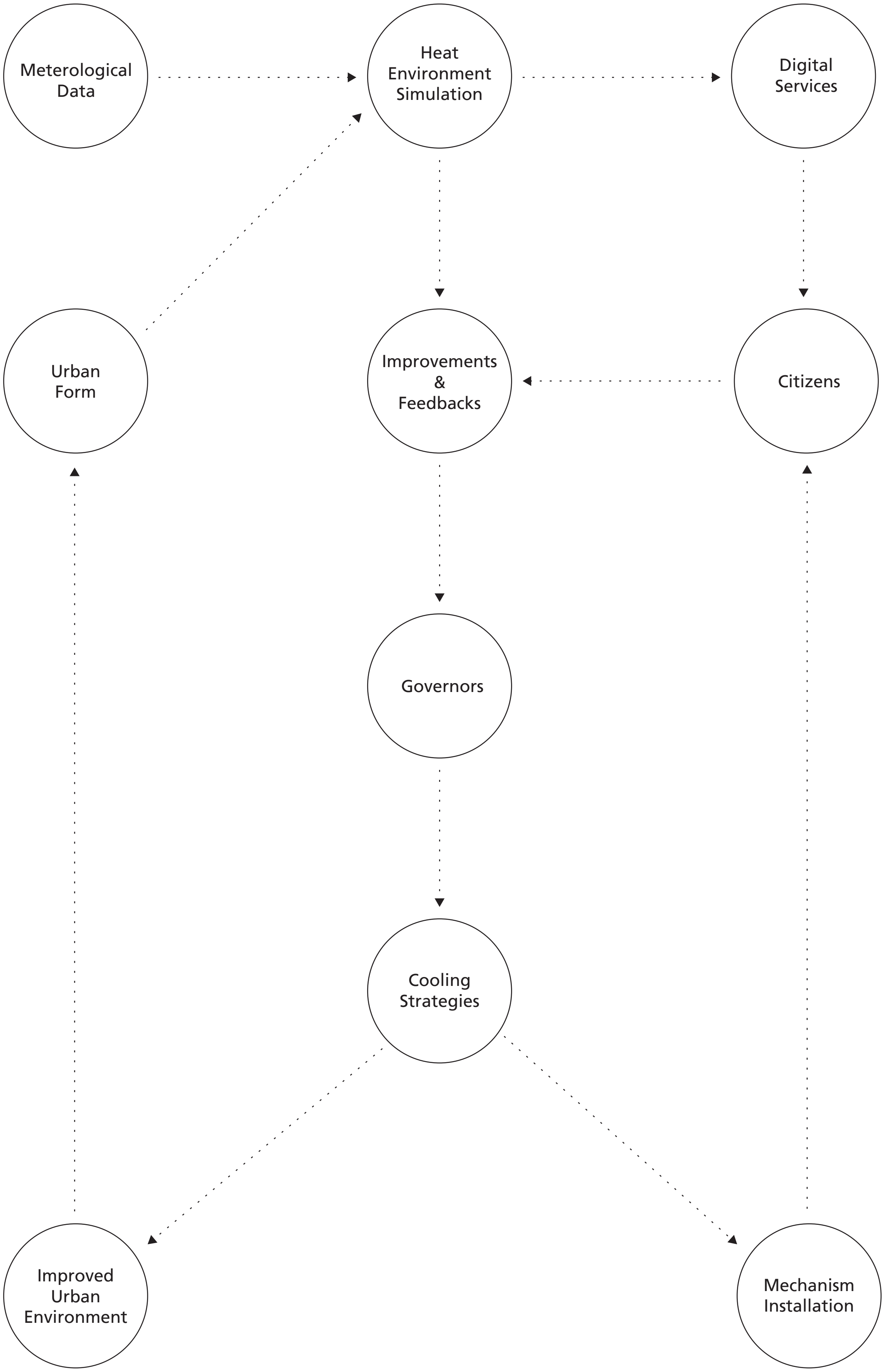


1.8 The “Angel” cooling mechanism in Singapore (W.Alsop, 2006).

Summary

It can be seen that the thermal environment is getting worse in Europe, posing a severe threat to residents, especially the elderly and those suffering from chronic diseases. Due to the complexity, the heat environment in the city will be affected by many factors.

The strategies that have been implemented so far have been verified to alleviate UHI effectively. However, except for cooling devices, other strategies are investigated and target in cities rather than people living in cities. The existing cooling devices also have defects in ecological and sustainable aspects. Therefore, there is still room for improvement in urban cooling strategies that can affect people effectively.



2.1 The workflow of the thesis.

II METHODOLOGY

The purpose of this research is to provide Helsinki with a set of feasible and ecological outdoor thermal comfort mitigation solutions under the severe climate in the future. In order to actualize the above objective, the following methodological procedures have been taken:

Describe the existing meteorology, urban form, and spatial distribution of Helsinki, and select representative area for thermal environment study.

Compare the characteristics of different thermal environment simulation models. Determine the analysis model and simulate the pilot area.

Define a set of practical mitigation strategies for the city based on the results of thermal environment simulation.

Explore the application of research and design results to provide citizens with valuable services. Meanwhile, a feedback platform is established to strengthen the interaction between residents and governors.

III OUTDOOR THERMAL COMFORT

Chapter Three reviews the indicators and simulation models commonly used to describe the human body's thermal perception in the urban context. The chapter establishes a comprehensive understanding of thermal environment simulation's current development by comparing indicators and platforms.

Outdoor thermal comfort research intends to ameliorate the urban heat environment, while human subjective perception is the direct method to evaluate. Although the questionnaire survey method used in the initial stage can immediately reflect the human body's subjective sensing, it requires mass human resources and large uncertainties. The outdoor thermal comfort proposes establishing the relationship between the external space and the human body's thermal sensation. These indicators assess the outside climate and predict heat perception with potential risks.

Outdoor thermal comfort index classification

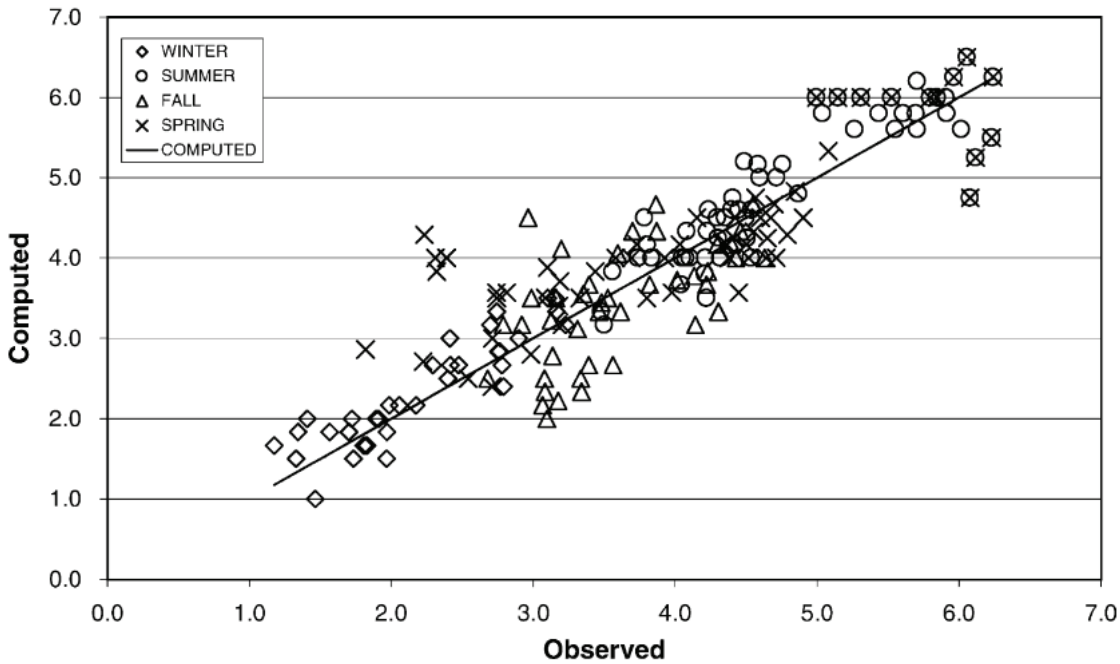
K. Blazejczyk (2012) divides the thermal sensation indices into two categories. One integrates multiple meteorological variables, and the other, which the latest researches focus on, derives from heat budget models.

1. Indices in early stage

Early studies establish heat risk judgments grounded on the relationship between meteorological parameters and thermal perception without heat balance. The indices, such as the Heat Stress Index (HSI), The WetBulb Globe Temperature (WBGT), the Heat Index (HI), and Humidex, explore the human body's thermal overwork and thermal damage under the damp heat condition (K. Blazejczyk, 2012).

R. Steadman (1979) defines the Apparent Temperature (AT) as in the same humidity level, the temperature producing the equivalent discomfort as the experience under the current ambient temperature and solar radiation.

B. Givoni (2003) brings out the Thermal Sensation (TS) based on regression analysis, which adds surface temperature as the parameter compared with the other indices.



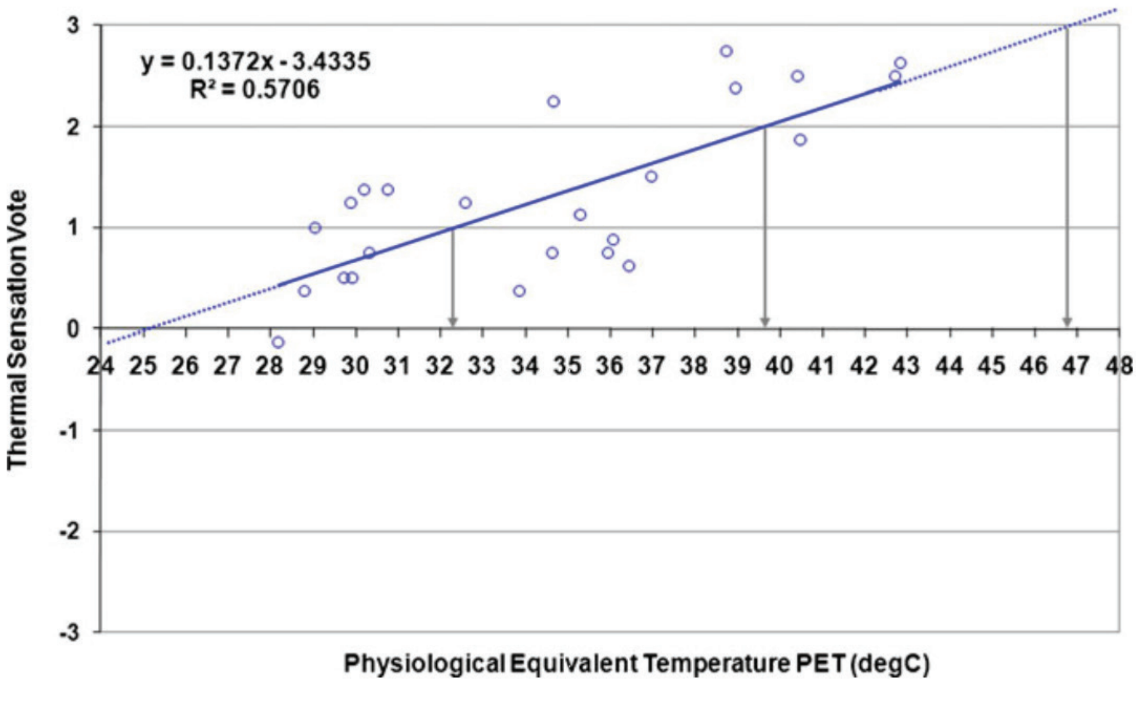
3.1 Thermal sensations in different seasons in Japan (B. Givoni, 2003).

2. Indices based on the steady heat transfer model

The steady heat transfer model assumes that the heat exchange between the human body and the environment keeps stable, which means the human body's thermal load is a fixed value. Due to similarities, outdoor thermal comfort indicators follow and correct from indoor indicators in the early stages.

Standard Effective Temperature (SET) was developed based on Effective Temperature (ET) by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) since 1923. J.Pickup (2000) adapts the SET model for outdoor application (OUT_SET) by introducing the Outdoor Mean Radiant Temperature (MRT) model.

Predict Mean Vote (PMV) is widely used in the thermal environment. P. Fanger (1973) defines PMV as "the difference between inner thermal production and the thermal loss to the practical environment for people retaining skin temperature and sweat production at an ideal value." However, the assumptions of the PMV model deviate from the actual situation of the human body in outdoors. The instability of exterior space and the human thermal adaption psychology leads to the deviation between PMV prediction and actual values (V. Cheng, 2012). Furthermore, PMV calculates inaccurately when the ambient temperature deviates significantly from the natural thermal environment (C. Skinner, 2001).



3.2 Correlation between actual heat sensation and predicted PET in summer (V. Cheng, 2012).

The Physiological Equivalent Temperature (PET) ameliorates the outdoor human body's temperature-regulating process based on a complete thermal budget model (H. Mayer, 1987). The PET model optimizes human outdoor regulation's functional status, whereas underestimating the latent heat dissipation on thermal sensation and overestimating thermal radiation's influence (V. Cheng, 2012).

Derived from the man-environment heat exchange model published by himself, Blazejczyk (2005) define the Physiological Subjective Temperature (PST) as the temperature formed around the cloth-covered skin surface after 15-20 minutes in a stable environment.

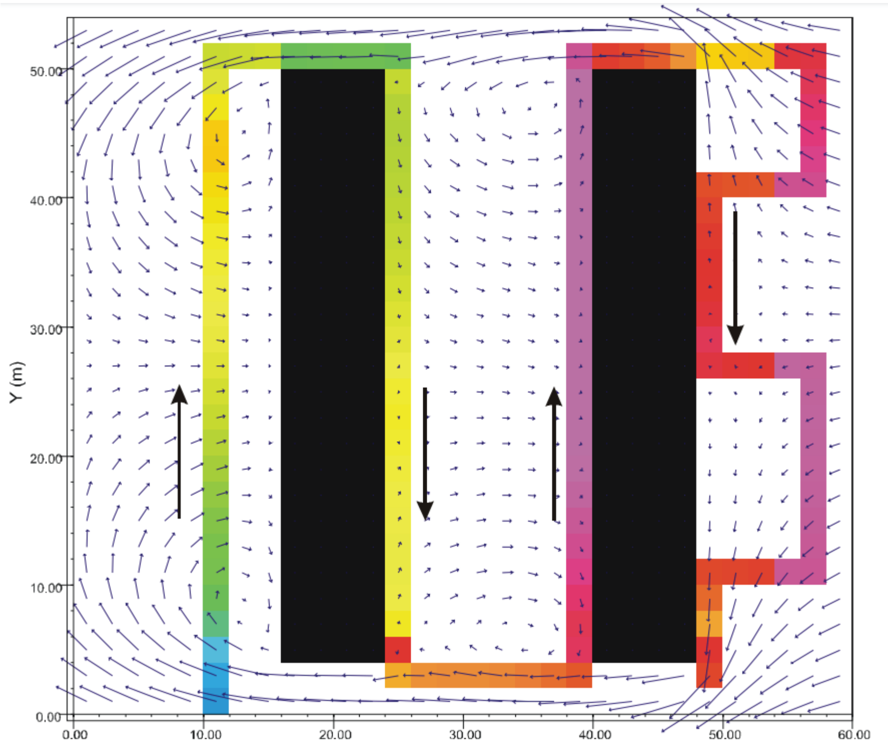
The COMFA is a body heat budget based thermal comfort model first established by Brown and Gillespie for landscape evaluation. To get adapted to the urban space, the COMFA+ model considers the impacts of constructions on solar radiation (A. Angelotti, 2007). As the imperfection part, the COMFA+ can only simulate the simplified urban spaces.

3. Indices based on dynamic heat transfer model

The thermal sensation in a dynamic environment is inconsistent from a stabilized environment. Contrary to the steady heat transfer model's assumptions, the human thermal load continually changes in the actual outdoor space. Both the human core temperature and skin temperature take a long time to reach the balance (P. Höppe, 2002). It takes a long time to reach a steady-state in daily life while the human body is exposed outside for a short time. Thus, the indicators based on steady-state comfort models (such as OUT_SET, PET, PST) all have defects.

According to the two-node and MEMI models, Bruce (2000) exploits the microclimate software ENVI-met to set up the dynamic Physiological Equivalent Temperature (dPET). dPET reflects the heat perception under transient condition through numerical simulation of step length calculation.

European Cooperation in Science and Technical Development Action 730 develop the Universal Thermal Climate Index (UTCI) deriving from the Fiala multi-node model of human heat balance. The UTCI is defined as the reference condition's air temperature, impacting the reference personnel's equivalent response as the actual environment (K. Blazejczyk, 2013). The UTCI, iteratively computed by the body temperature regulation model, accurately reflects the thermal sensation changes with physical exposure time under different climatic situations (K. Blazejczyk, 2012).



3.3 Simulated thermal perception in the selected route by dPET (M. Bruce, 2000).

Outdoor thermal comfort indices comparison

The environmental and body parameters are essential aspects of the thermal comfort index. The indices based on regression analysis (WBGT, AT, and TS) exhibit a careful consideration of environmental parameters. Furthermore, the rest two index groups append the body aspects to the heat risk indicators.

The majority of indicators refer to the equivalent temperature concept, using temperature as the export units to deliberate the thermal perception and establish temperature ranges corresponding to different sensations. Some indicators adopt a heat budget to reflect the gains and losses of the body.

WBGT, Humidex, HI, and SET are suitable for evaluating hot climate such as low latitudes from the sensation interval. PET, PST, UTCI own a more comprehensive applicable temperature range due to relatively complete sensation zones.

	WGBT	HI	Humidex	HSI	AT	TS	SET	OUT_SET	PMV	PET	PST	COMFA	UTCI
Ambient temperature	●	●	●	●	●	●	●	●	●	●	●	●	●
Humidity	●	●	●		●	●	●	●	●	●	●	●	●
Wind speed	●				●	●	●	●	●	●	●	●	●
Radiant heat transfer	●			●	●	●		●	●	●	●	●	●
Skin temperature							●	●	●	●	●	●	●
Skin moisture							●	●		●	●		●
Clothing resistance							●	●	●	●	●	●	●
Human metabolism							●	●	●	●	●	●	●

3.4 Related parameters of various thermal comfort indices.

	WGBT	HI	Humidex	SET	PMV	PET	PST	COMFA	UTCI
Unit	℃	℃	℃	℃		℃	℃	W/m2	℃
Frosty							<-36		<-27
Very cold					<-3	<4	-36--16		-27--13
Cold					-3--2	4-8	-16--4	<-150	-13-0
Cool				<17	-2--1	8-18	4-14	-150--50	0-9
Comfortable	<18		20-30	17-30	-1-1	18-23	14-24	-50-50	9-26
Warm	18-24	27-32	30-40	30-34	1-2	23-35	24-34	50-150	26-32
Hot	24-28	32-41	40-45	34-37	2-3	35-41	34-44	>150	32-48
Very hot	28-30	41-54	45-55	>37	>3	>41	44-54		38-46
Sweltering	>30	>54	>55				>54		>46

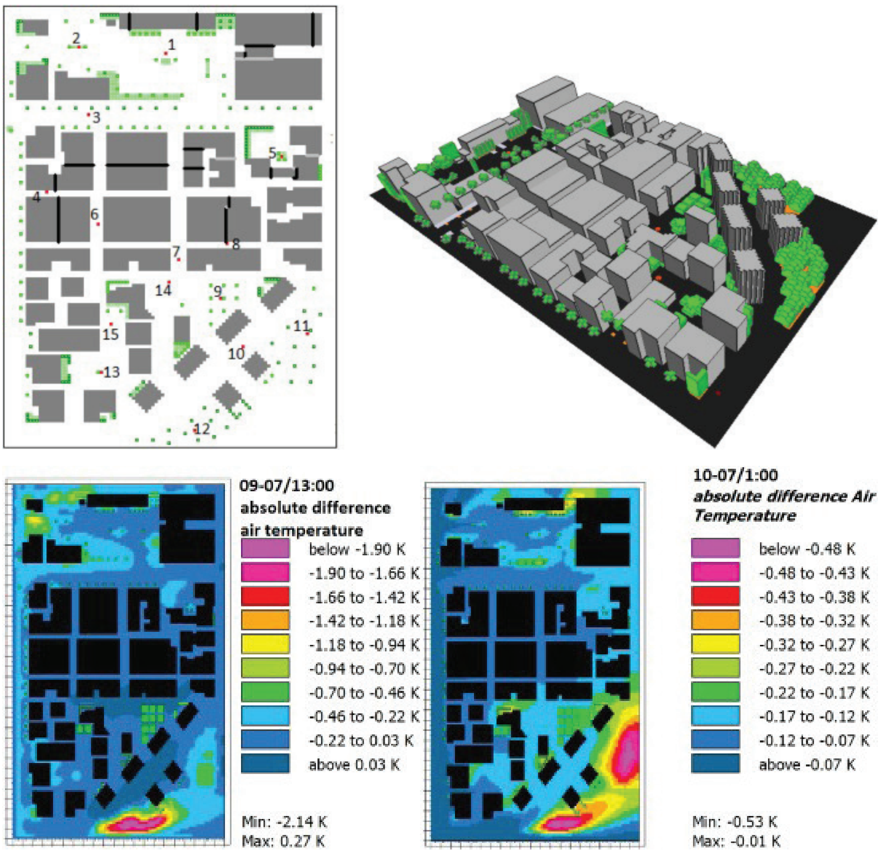
3.5 Thermal sensation of various thermal comfort indices.

Outdoor thermal comfort application

1. Common simulation methods

The outdoor thermal comfort index calculation requires a software platform's support due to human body parameters' involvement. Many simulation methods are developed for research or commercial purposes, and the most frequently used software is listed as follows.

The Envi-met is one of the most usually applied dynamic simulation models to simulate an urban microclimate environment. Based on the grid level, the Envi-met computes the comfort indices through complex iterative operations of interactions between urban context and meteorological aspects (S. Tsoka, 2018). On the one hand, the model includes the most comprehensive aspects, and the result can illustrate every single value in three-dimensional grids. On the other hand, it is unaesthetic in the urban design process as elements are constructed in pixel units. Moreover, the software needs a high capacity carrier where the process will take more than one day with a large scale area.

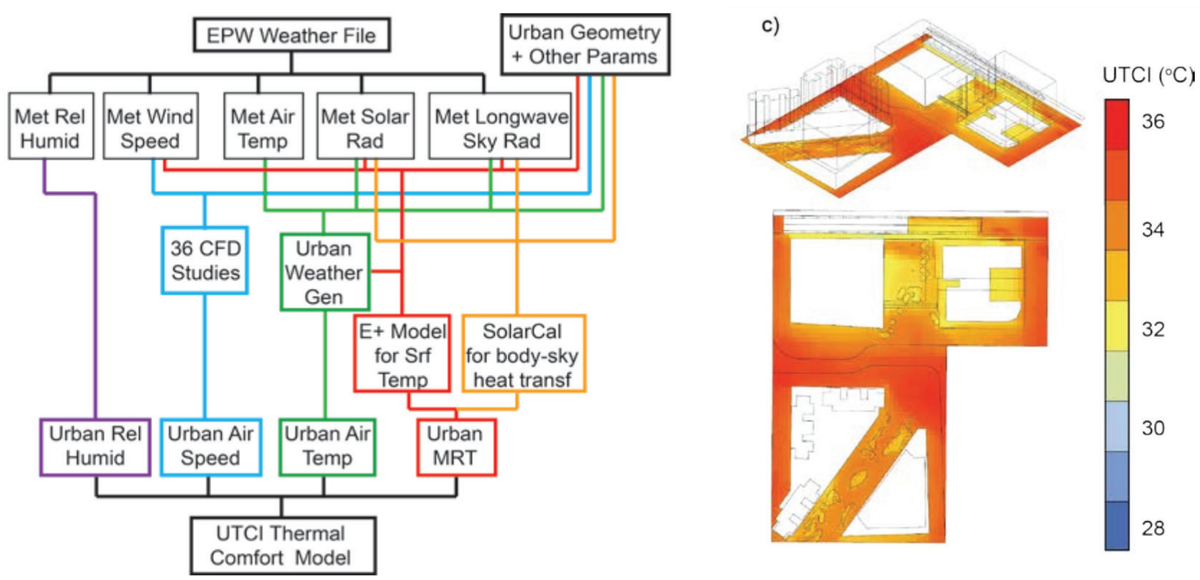


3.6 The pedestrian thermal comfort simulation in dense urban block by Envi-met (J. Fahed, 2020).

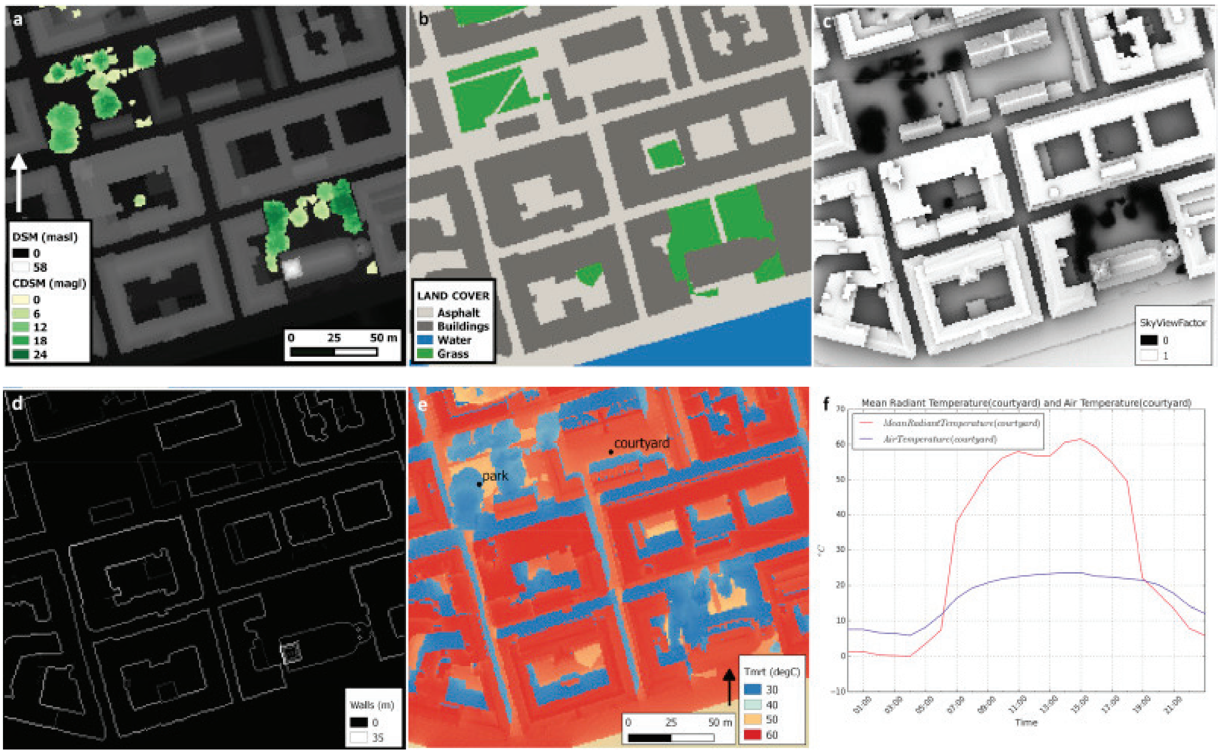
B. Bueno (2010) published Urban Weather Generator (UWG) on the grasshopper platform to analyze the UHI effect in urban canyon and its impact on architecture energy performance. The plugin is continuously under contribution. The latest release can calculate the UTCI index combining with the Ladybug plugins. The UWG focus on neighborhood-scale simulation of the urban canopy layer heat exchange produced by buildings. Unfortunately, the plugin lacks some environmental parameters, such as the effect of water evaporation.

The Solar Longwave Environment Irradiance Geometry (SOLWEIG) model is another outdoor thermal environment simulation model (F. Lindberg, 2018). The software calculates radiant fluxes and MRT from Digital Surface Models (DSM). The model simplifies three-dimensional geometries into raster images with elevation information, which reduces the workflows and time-consuming. However, the SOLWEIG model only supports points-based PET and UTCI calculations in the newest version.

Another frequently used model is Rayman software. It calculates the sunshine duration, shadow space, radiation flux, and thermal relevant indices assessment by inputting small meteorological data quantities (A. Matzarakis, 2010). The limitation exists due to incompatibility with low solar angles and the unexplainable shortwave radiation reflection.

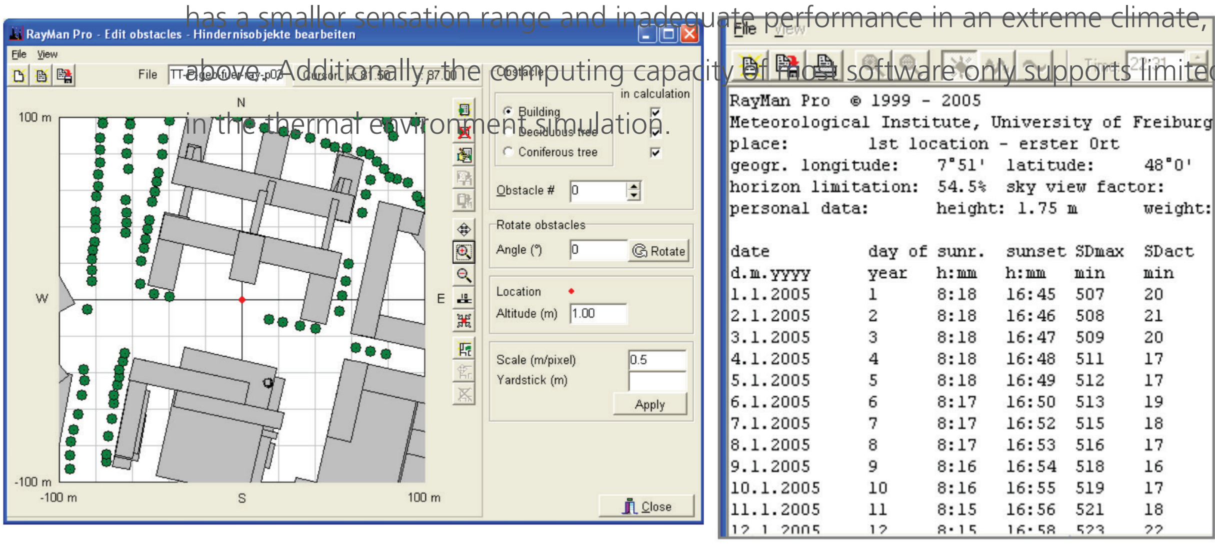


3.7 The workflow of UTCI calculation in grasshopper platform (C. Mackey, 2017).



3.8 The SOLWEIG model analyse Tmrt basing on raster images (F. Lindberg, 2018).

Most indicators software outputs are PMV corrected with outdoor solar radiation factors, which has a smaller sensation range and inadequate performance in an extreme climate, as mentioned above. Additionally, the computing capacity of most software only supports limited urban scale in the thermal environment simulation.



3.9 The working panel and data ouput of Rayman software (A. Matzarakis, 2007).

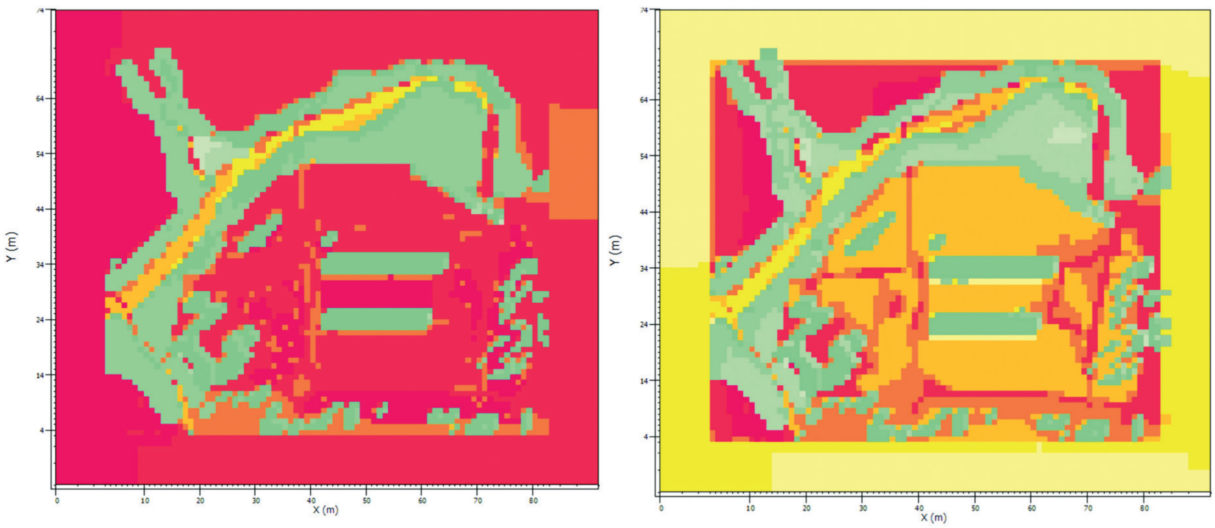
2. Feasibility verification of software

Varieties of software and platforms are certified to simulate the outdoor thermal comfort in an urban context effectively. Through utilizing the PMV model and COMFA+ model in ENVI-met software, G. Latini (2010) evaluates the thermal environment of a redevelopment area in Ascoli Piceno. N. Gaitani (2007) adopts COMFA and modified TS models to calculate the thermal comfort conditions in a specific area of Athens and verify potential thermal environment improvement measures' effectiveness.

G. Latini (2010) confirms that the different pavings materials affect thermal comfort. Shading devices determine a more robust performance than the green surface in local comfort. N. Kántor (2018) assesses three different modeling software (ENVI-met, SOLWEIG, and RayMan) by simulating the mean radiant temperature (MRT) of Bartók square in Szeged. Kántor points out the essentiality of trees and artificial shading for mitigating heat stress in pedestrian level.

S. Thorsson (2017) applies the SOLWEIG model to predict high MRT hours from 2017 to 2100. M. Asghari (2019) analyses the 15 years of thermal outdoor discomfort in Iran using UTCI, PET, and PMV indices.

Most indicators software outputs are PMV corrected with outdoor solar radiation factors, which has a smaller sensation range and inadequate performance in an extreme climate, as mentioned above. Additionally, the computing capacity of most software only supports limited urban scale in the thermal environment simulation.



3.10 The comparison of PMV values between asphalt and grass as the paving (G. Latini, 2010).

Software or Platform	Supported Indicators				
Wincomf	ET	SET	PMV		
scSTREAM		SET	PMV		
Thermal Comfort	ET	SET			
Townscope II			PMV	PET	
RayMan		SET	PMV	PET	
ENVI-met			PMV		
BioMet			PMV	PET	UTCI
SOLWEIG				PET	UTCI
UWG					UTCI

3.11 supported indicators on various platforms.

Summary

Overall, the early heat risk indicators cannot accurately illustrate the actual thermal sensation because of lacking the human body parameters. Now it is mainly used in meteorological reports, which do not require high accuracy of thermal evaluation.

The interval provided by PET, PST, and UTCI is reliable from thermal sensation interval distribution. Consequently, the corresponding evaluated environment is also broader. Although the COMFA model covers a wide range, the output unit is not intuitive. Combined with software platform support, PET and UTCI are adequate for outdoor thermal environment assessment.

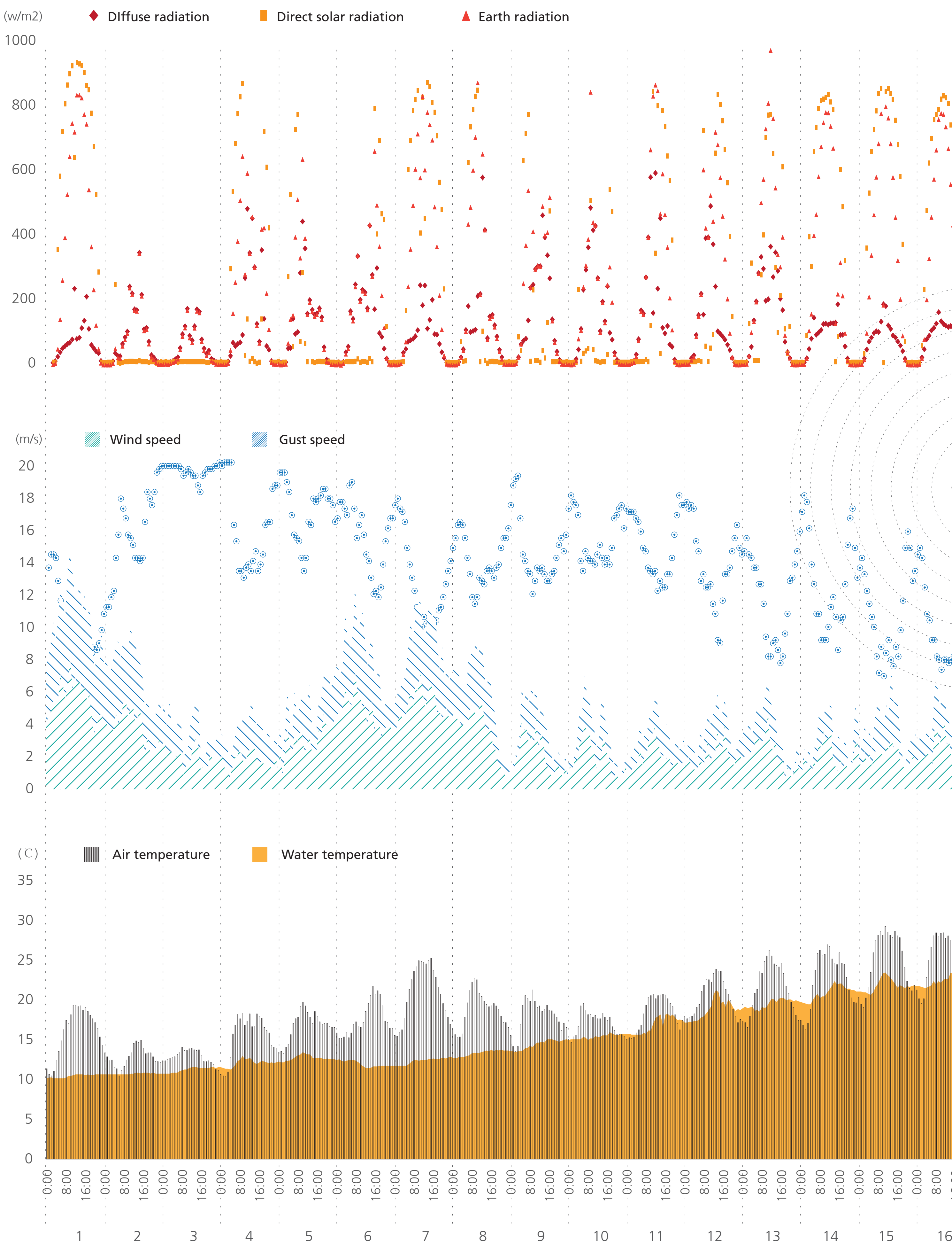
For city level simulation, the Envi-met is more comprehensive with requiring a high capacity carrier. The Grasshopper concentrates on building performance. The SOLWEIG model simplifies the complexity and time-consuming calculation comparing with Envi-met.

IV THE CONTEXT OF HELSINKI

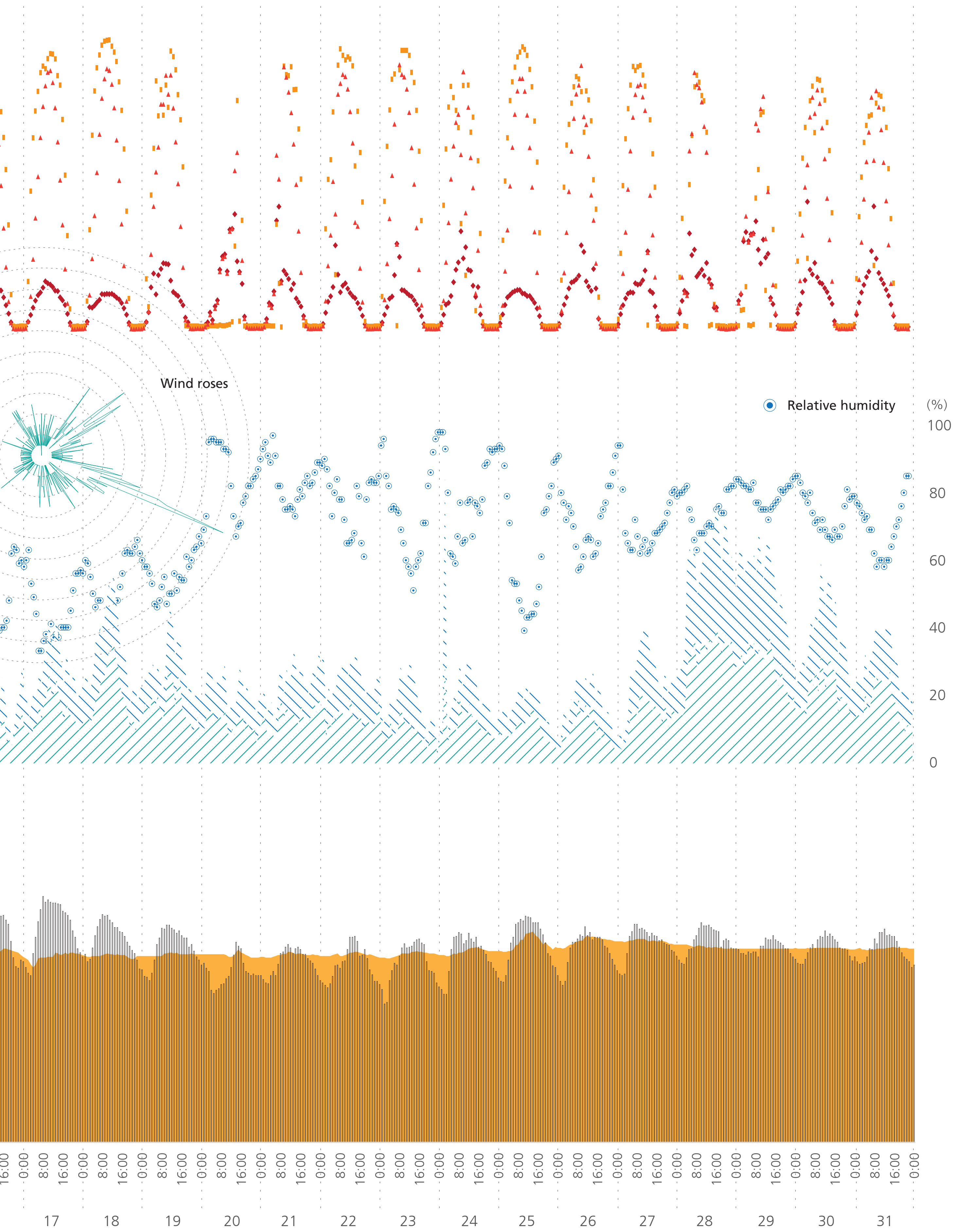
Chapter Four analyses the Helsinki context into meteorology, morphology, and population distribution. Understand the information about the city and determine the scope of further research.

Heatwave summer in 2018

The summer of 2018 was the warmest season in Finland's history with a full 2 degrees higher than the average. The uniqueness of 2018 was that not only did the heatwave last a prolonged unbroken period, but also little rain fell in Finland (Finnish Meteorological Institute, 2019). The institute also disclosed that most years in this decade (such as 2011,2013, 2014, and 2015) had shattered the heat records.



4.1 Meteorological information recorded in July 2018.

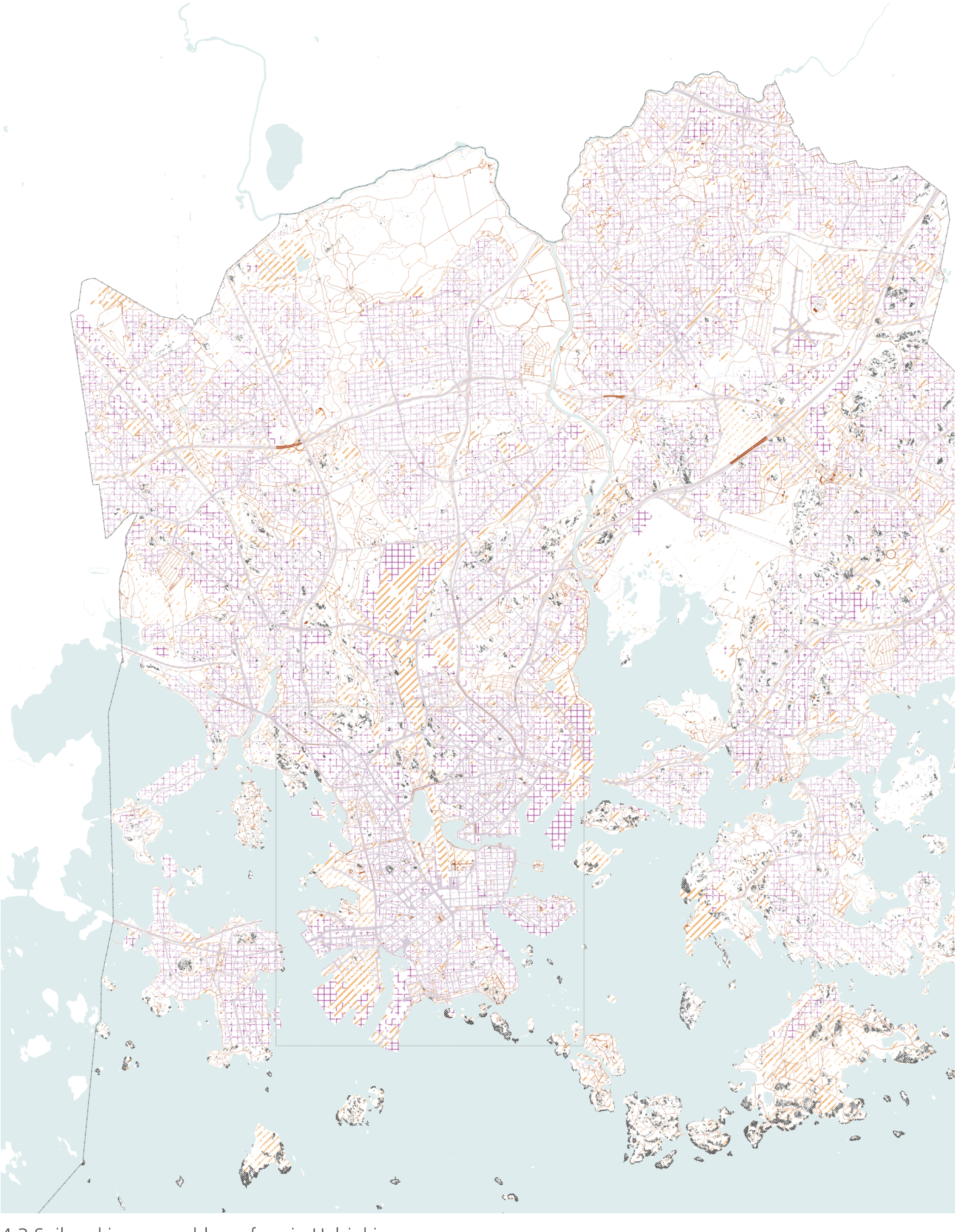

Wind roses
Relative humidity
(%)
100
80
60
40
20
0
16:00 0:00 8:00 16:00 0:00 8:00 16:00 0:00 8:00 16:00 0:00 8:00 16:00 0:00 8:00 16:00 0:00 8:00 16:00 0:00 8:00 16:00 0:00 8:00 16:00 0:00 8:00 16:00 0:00 8:00 16:00 0:00 8:00 16:00 0:00 8:00 16:00 0:00 8:00 16:00 0:00 8:00 16:00 0:00 8:00 16:00 0:00 8:00 16:00 0:00
17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

4.2 Green landcover in Helsinki.

Factors of landcover

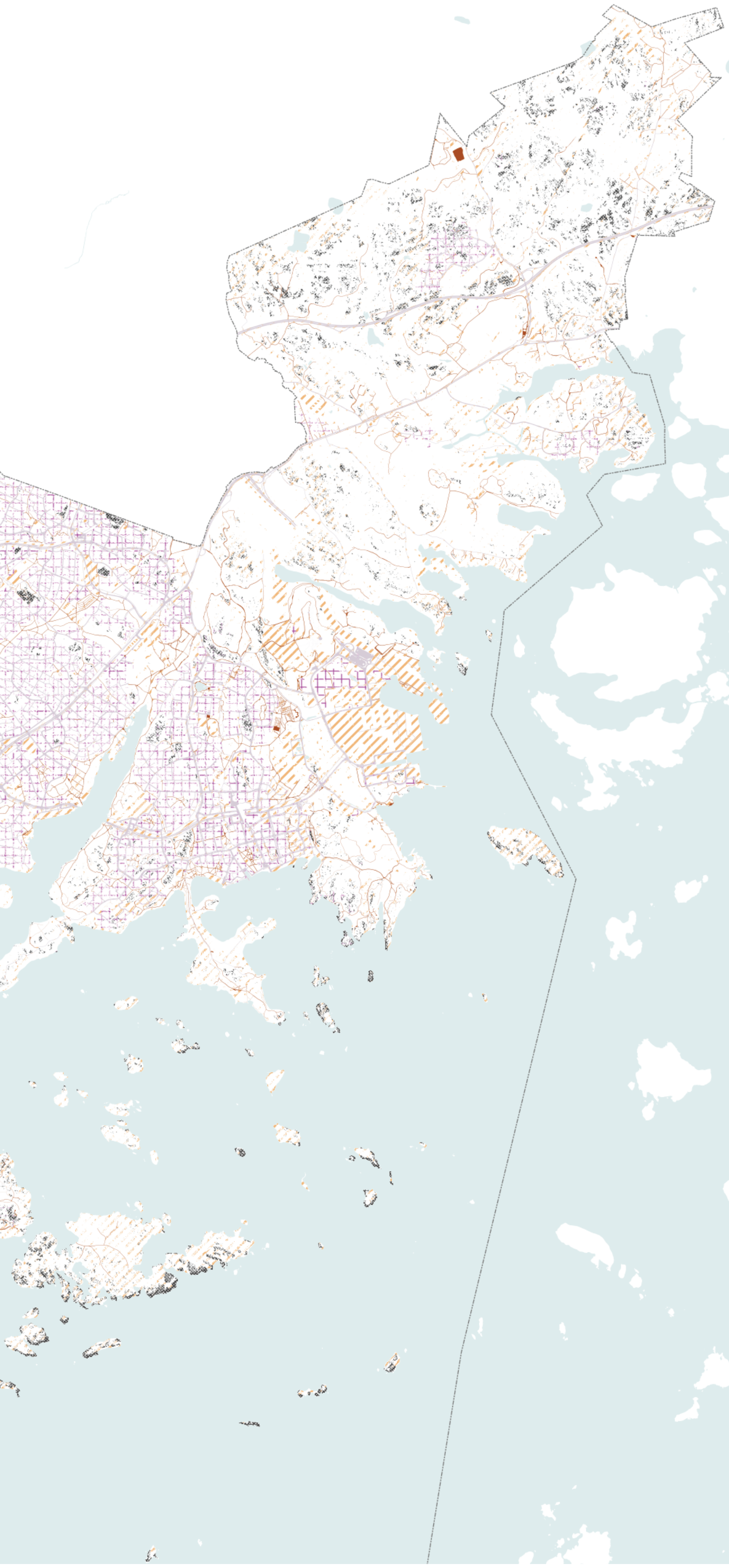
Previous studies about outdoor thermal comfort simulation reveal that landcover impacts heat stress received by the pedestrian.

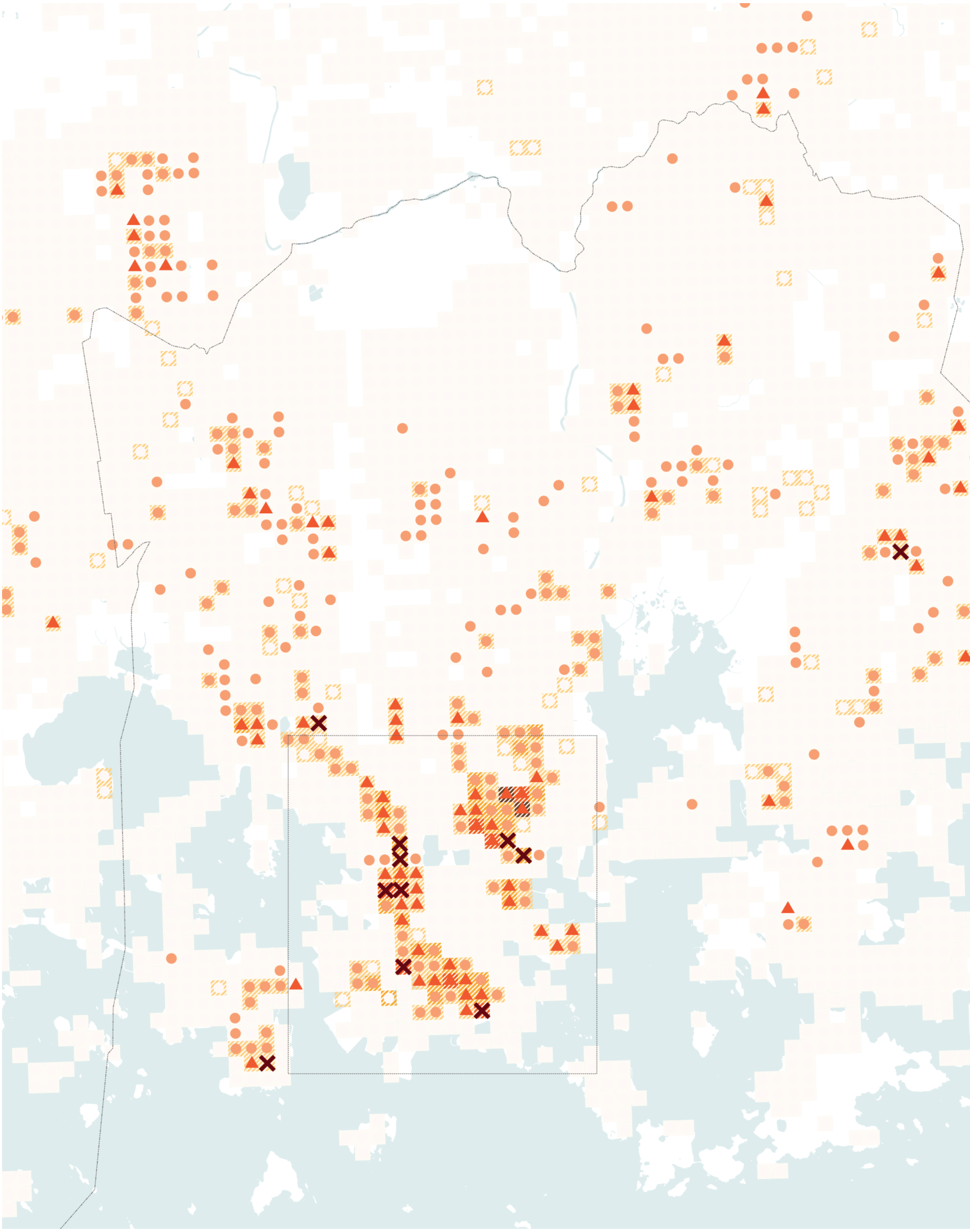
Vegetation and water cover most of the city where the distinct “green finger” radially extends from the center. Large green and blue infrastructure ventilate the urban fabric and promote the microclimate. Besides, trees and other shadings also contribute a lot in assimilating direct solar radiation.



4.3 Soil and impermeable surface in Helsinki.

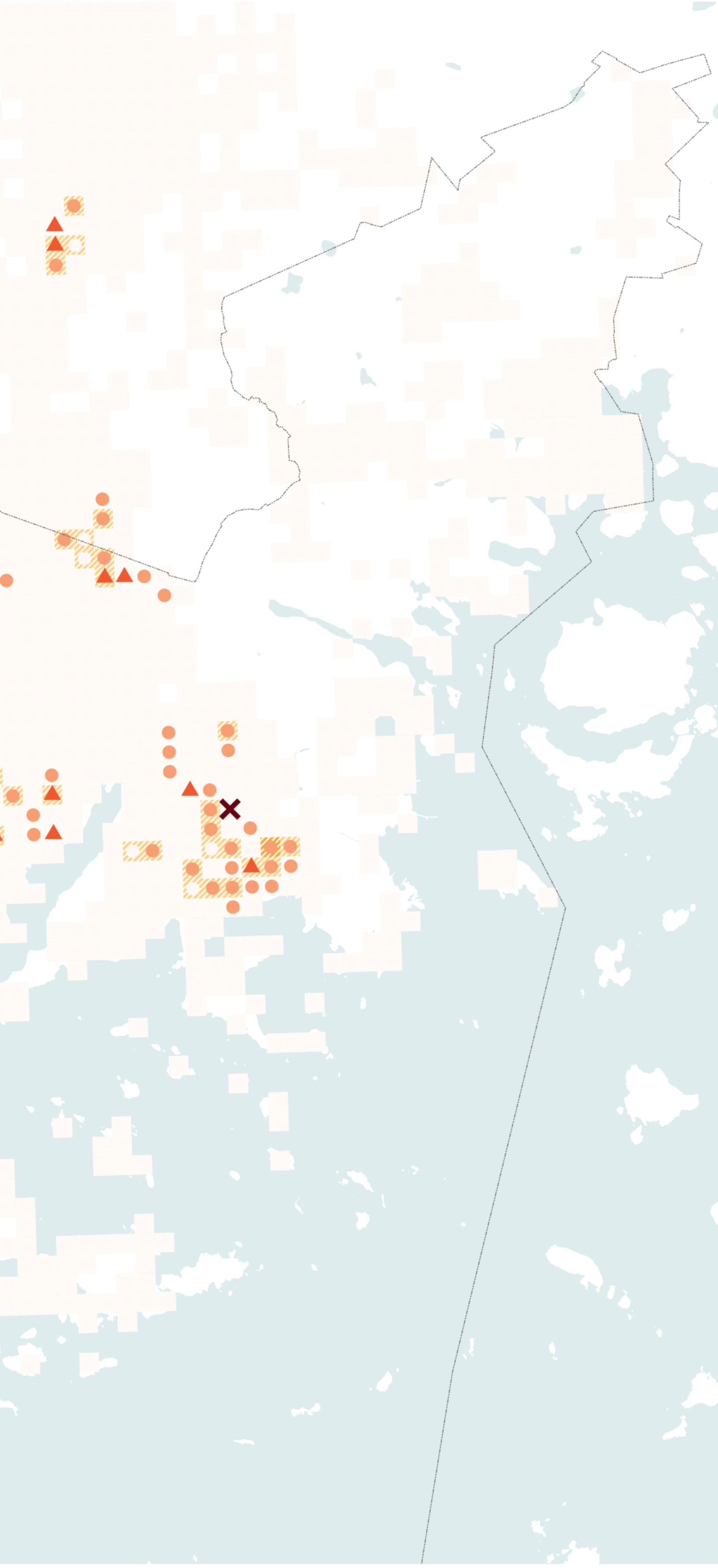
Diverse covering materials possess different solar radiation reflectance and absorption rates. Impermeable materials have been broadly adopted in urban constructions.





4.4 Population density and elderly group distribution in Helsinki.

Factors of vulnerability



According to Statistic Finland (2010), people spent more time on outdoor activities from 1987 to 2010. Besides, the majority of senior citizens live independently (E. Karvinen, 2012), so the elderly inevitably need to go out alone for activities or essential items. Previous studies illustrate that the heatwaves impact the mortality of citizens. Especially the elderly population stays in a critical condition when exposed to the extreme heat environment.

From the city level, most population and older adults (over 65 years old) distribute in the city center, which is also in poor green condition and paved with vast impermeable materials.

Numbers of population per km2

<10000

10000-20000

20000-30000

30000-40000

>40000

Elderly people(65+) per km2

<1500

1500-3000

3000-4500

>4500

0 2.5 5km

The Context in the City Center

The city center here is not a specific district but a total area where constructions and infrastructures concentrate.

The building blocks gradually dilute from the middle to the periphery, and most are commercial and official constructions. Furthermore, The well-developed traffic network runs throughout the whole city. It leads citizens here to attend public activities.

Solid pavings cover most of the area, which creates flat spaces but increases the radiation reflectivity. The water bodies encompass the area where most of the green space is located around. However, only small green spaces exist in the dense construction area.

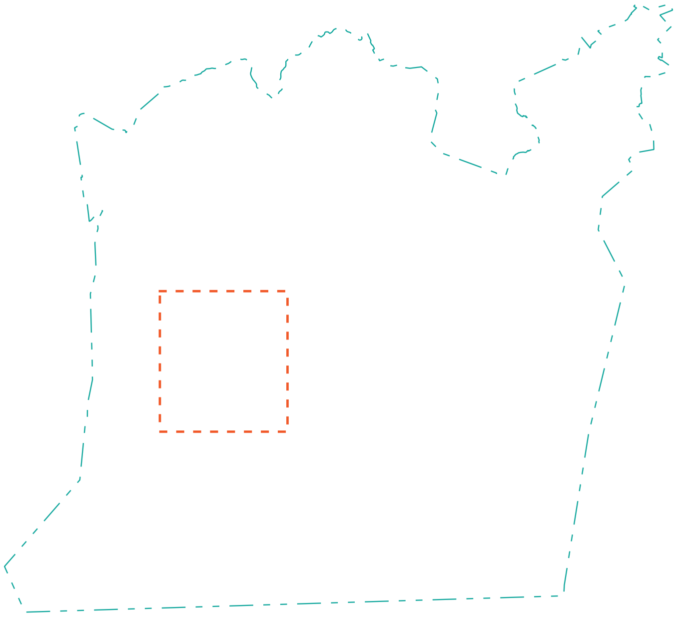
Street and public transport

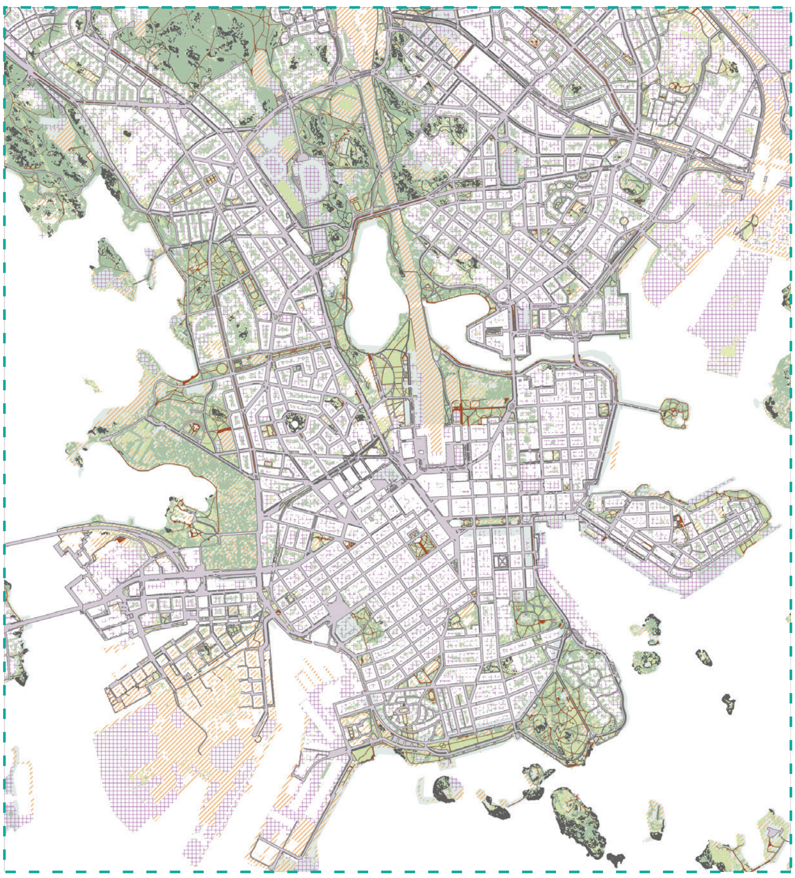
Urban Fabric

Train station · Rail track · Bus stops · Building

Metro station · Metro line · Road

4.5 The urban context in pilot area.





Land cover

Tree covered
Low vegetation covered
Bare ground
Cliff
Impermeable surface
Paved road
Dirt road
Green areas

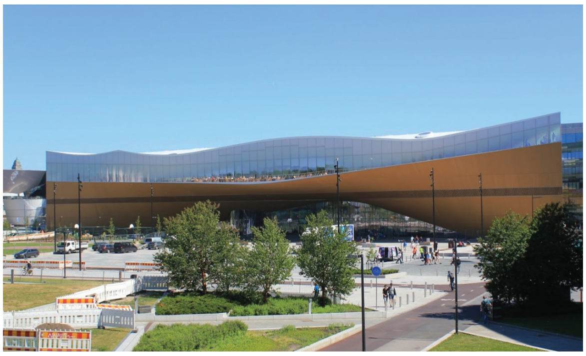

Commercial building


Residential street


Transport street


Parking space

4.6 The urban images in Helsinki.

Open space


Green space

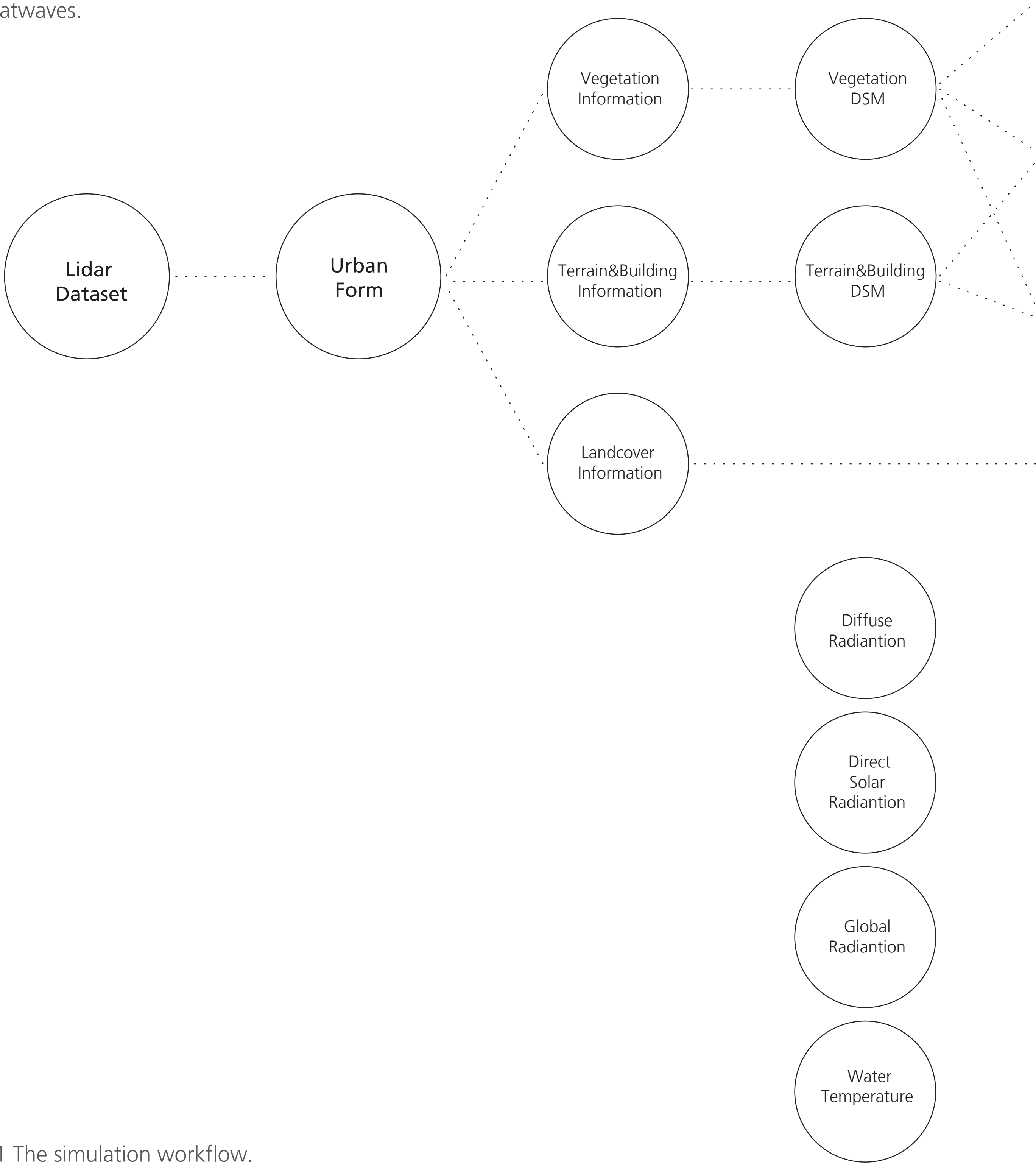

Water front


Dock

(Source: Google map)

V THE HEAT ENVIRONMENT OF HELSINKI

Chapter Five illustrates how the heat environment is simulated. Based on one selected day simulation, the chapter evaluates the performance of different Helsinki spaces when exposed under heatwaves.



5.1 The simulation workflow.


Incoming Longwave Radiantion
Vegetation (sky facor)
Incoming Shortwave Radiantion
Building (sky factor)
Direct Longwave Radiantion
Mean Radiant Temperature
Shadow Pattern
Direct Shortwave Radiantion
Ground Factor
Outgoing Longwave Radiantion
Meterological Data Package
Outgoing Shortwave Radiantion
Apparent Temperature
Wind Speed
Air Temperature
Relative Humidity
Water Vapour Pressure

The simulation workflow

1. Data description

The input data consists of the city lidar dataset and the meteorological parameters. The lidar data is a three-dime age of queues is 50%. Due to the errors, the land use information overlays to reclassify the point attribute and r lidar dataset.

The meteorological data measured by the Kaisaniemi weather station contains seven parts: air temperature (°C), (w/m2), direct radiation (w/m2), and global radiation(w/m2). The minimum air temperature was 10.4 °C on 4th . nating wind direction over the Helsinki was the south-east, followed by north-east in July. The recorded hourly w 10.2°C to 25.9°C. Therefore, the research takes climate data on 15th July to simulate the outdoor heat environm

5.2 The Helsinki LIDAR set taken in 2018 tansformed to Digital Elevation Map and sky view factor for thermal sir

ensional point set scanned at 550m height in 2018. Dot density in the nadir was 21 points/m2, and side cover-
epatch the blank area. The urban geographical information and digital model are derived from the reclassified

water temperature (°C) in 20 cm depth, relative humidity (%), wind speed (m/s) at 10 m high, diffuse radiation
July 2018 and reached 30.2 °C on the 17th. The relative humidity fluctuated between 33% to 99%. The domi-
vind speed reached up to 8.3m/s and minimized to 0.5m/s. The water temperature ascended continuously from
ment.

mulation (Data form Helsinki Map Service, 2017).

2. Methods

The research area is a rectangular square of 5km * 5.5 km in Helsinki. Considering the spatial scale and calculation duration, the SOLWEIG model is more suitable. Overlaying the DSMs in a specific format with input meteorological data, the model will analyze longwave and shortwave radiation fluxes individually. The summarisation fluxes density will figure out the Tmrt through the Stefan-Boltzmann law. The Tmrt index is the essential parameter of UTCI. The UTCI calculation in a mathematical term as

UTCI = f (Ta; Tmrt; va; vp)
= Ta + Offset (Ta; Tmrt; va; vp) (K. Blazejczyk, 2013)

Using the SOLWEIG model on the Geographic Information System (GIS) platform, the simulation faces the following technical challenges: Currently, the latest SOLWEIG can only support the UTCI calculation in specified points. In order to overcome this problem, this research composes a script to calculate the UTCI in the whole region.

When the Tmrt is computed, the generated raster images from the SOLWEIG will be transferred into a numerary array that records the value information. The script will read the array as a loop and do a mathematical calculation of the UTCI. The results will be returned as a new array and form a new raster dataset.

The UTCI calculation formula refers to J. Ramsden (2015). The script refers to the appendix for further details.

```
ncols         2500
nrows         2750
xllcorner     25494000
yllcorner     6670500
cellsize      2
NODATA_value  -9999
35.7723190695731 2 28.596755115323333 35.701525526684584 28.858435936105895 34.87094575149437 34.95236991363733
35.743641287496885 28.90970107156752 29.31841375444312 29.228760312462207 29.329146458283795 29.40382707041292
35.79676113526119 34.97601283252518 29.26743613965032 29.43841620382814 29.30790786135002 36.30455689184433 36.
35.77089412456164 35.037209613606635 35.188505196117006 29.389849703821508 29.57365269778456 7 36.20993661550187
35.85344116845355 35.77557238909672 35.031178464521645 35.00016083666029 29.519339246552697 36.210949898730675
35.84817281935876 35.81333150950874 35.039866235561234 35.0367184855936 29.492393433221935 36.184409606268446 3
35.79506684655143 35.87490654259991 35.05901738132683 35.03524253956737 29.532941711744993 36.18290170816816 35
35.792419448803564 35.07808785126735 35.0399527524878 35.032718102807934 36.149421938541835 36.12264494673387 3
35.79073263267644 35.069775420135386 35.05322695512858 35.129172854882256 35.21438219008686 35.06501346021778 3
35.80594295237294 35.06783709089395 35.063672838302836 35.039359855291984 35.053036139027014 35.041497319086844
35.809608326504076 35.8146271467093 35.845998358907174 35.85768381423044 35.842478278531715 35.80322784575135 3
35.836097895642716 35.82805113474901 35.811672861665215 35.79687459081597 35.82596181842344 35.79605014346387 3
35.83779131699096 35.09789395456523 35.81327857446957 35.79612578118871 35.802398421589224 35.78278218332641 35
35.83109806168299 35.07851515101944 35.834573281787456 35.80292027912978 35.78663521114853 35.748972007266296 2
35.82785203457801 35.84221117949765 35.035547909838456 35.03284788920876 35.78546772290392 35.7290752437275 28.
35.82626425600633 35.841878564359725 35.05031632635328 35.04401385850181 35.77574387825223 35.72640548374763 35
```

5.3 The calculated UTCI index in numerary array form.

Heat environment in Helsinki

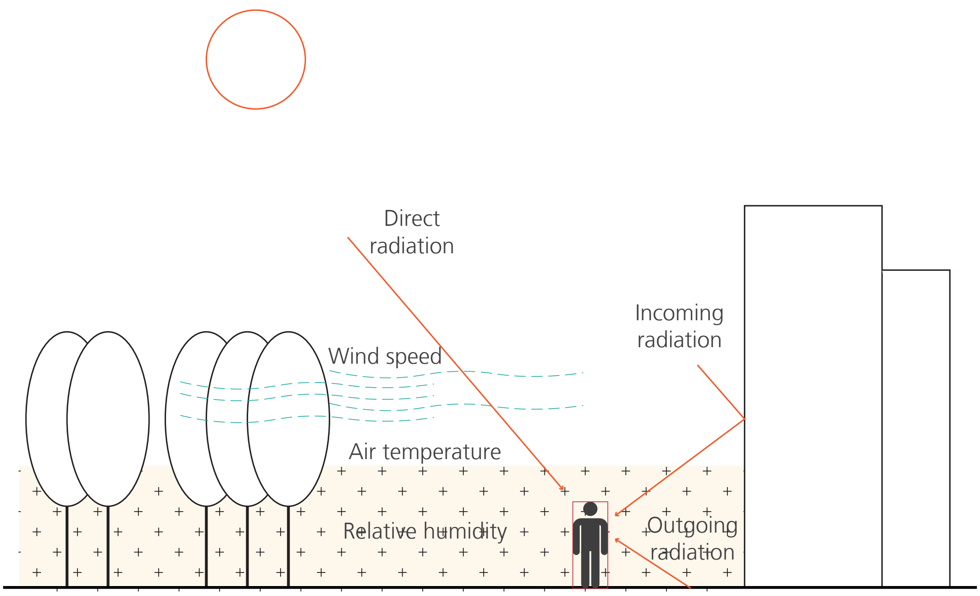
The study simulates the outdoor thermal environment from 7:00 to 19:00 on 15th July. The resolution is set to 2 meters in order to reduce the amount of computation while ensuring accuracy. The result value represents the human body's actual temperature at the height of 2 meters in this space. What is more, the simulated building roof temperature and water surface temperature are removed from the map since they are independent of the body's actual temperature.

1. Inadequacy of the simulation

The model computes the apparent temperature in the urban context based on total radiation flux and meteorological data. However, there are still some areas for improvement.

At the moment, buildings share a fixed value of albedo in the calculation, and without considering energy exchanges between the building and the environment. The buildings' albedo is diverse due to different surface coverage, such as construction materials and vertical greening. Different types of constructions, exceptionally official and commercial buildings, will produce a large amount of heat exchange and impact the surrounding space.

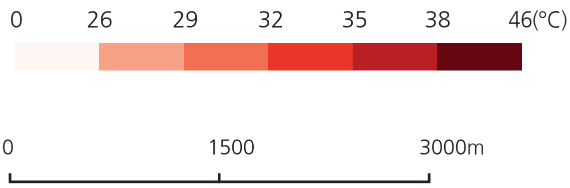
Moreover, the input geometrical type needs to be enriched, for instance, the classified albedo of different paving materials and tree species other than evergreen and deciduous.



5.4 The simulation diagram.

2. Heat environment simulations

As the maps illustrate, thermal pressure began to appear in the local central area from 9:00 and reached its maximum at 11:00. The thermal pressure continued until 17:00, when most of the area returned to an acceptable level. At 19:00, the whole area accomplished a thermally comfortable state.



7:00

13:00

15:00

5.5 Apparant temperature at different time on 15th July 2018.

9:00

11:00

17:00

19:00

3. Conclusion

Consistent with the analysis from Latini (2010) and Kántor (2018), green and construction shelters can effectively reduce heat perception. A plot under the tree or building shading can be 7 or 8 °C lower than the plot on the same landcover without shading. However, compared with other paving, grassland has an inconspicuous impact on thermal pressure relief with approximately 1 °C difference, which does not match the simulation results from Latini (2010).

Architecture is a contradiction to the thermal environment. On the one hand, the shadow of the building declines the body temperature effectively. On the other hand, the space near the sunny side of the building will be about half Celsius higher than the street temperature. In other words, whether the impact of the building on the ambient space is positive or negative depends on different times of the day.

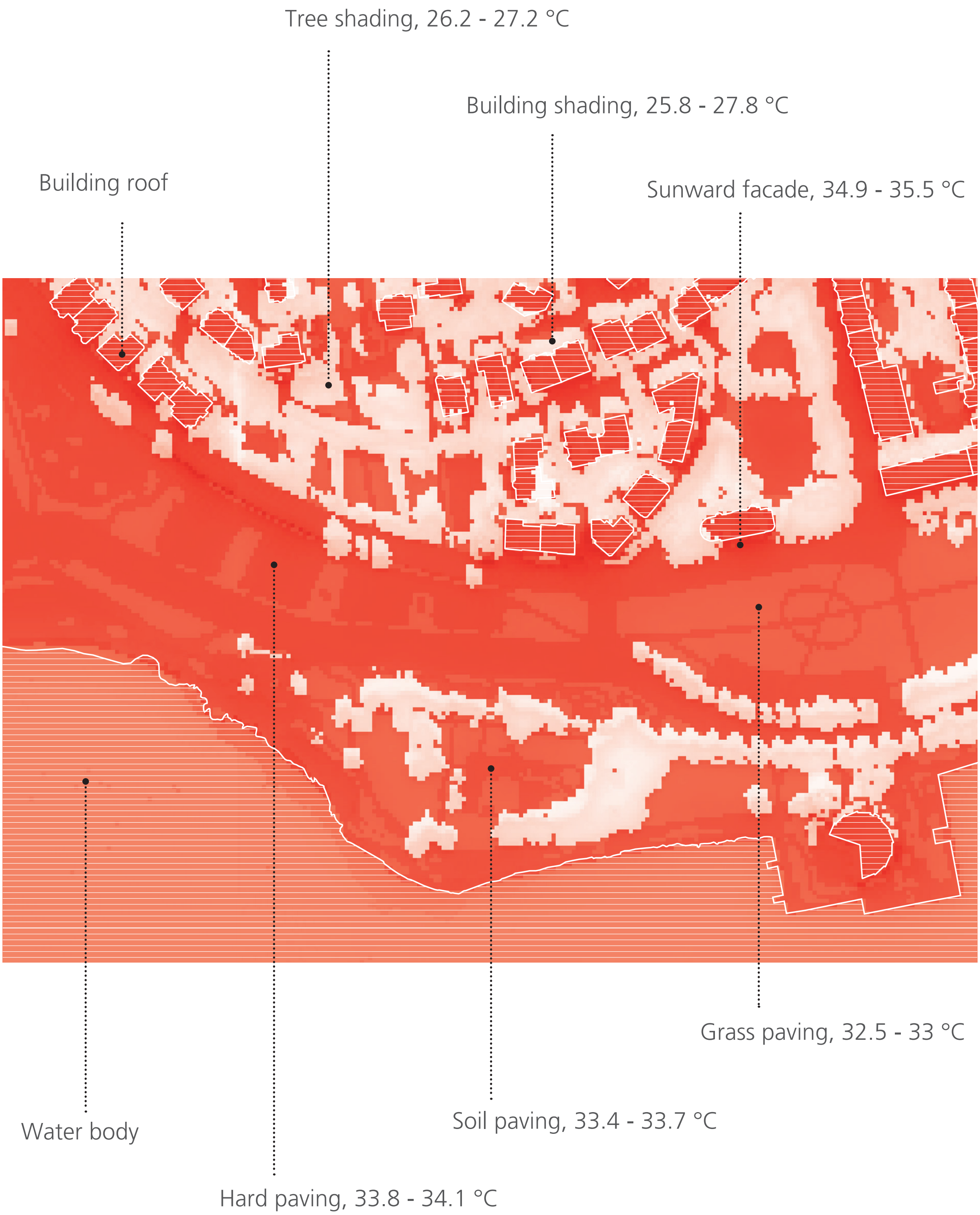
In general, wharves, open arterial roads, and public open spaces such as squares and artificial parks are the most thermally stressed areas due to lack of shelter from trees or buildings.

Summary

The chapter simulated the outdoor thermal sensation in Helsinki on 15th July 2018. It illustrates that the heatwaves in Helsinki only exist during the day, and the temperature at night will return to normal.

The open space without shading has very high thermal stress on the human body in summer. Moreover, changing surface materials shows few improvements in human perception in simulation, while tree canopy is a reliable measure to reduce thermal perception. Some measures, such as green roofs, cannot be simulated due to the software itself.

Air temperature: 28.2 °C



5.6 Apparant temperature at different space at 13:00 on 15th July 2018.

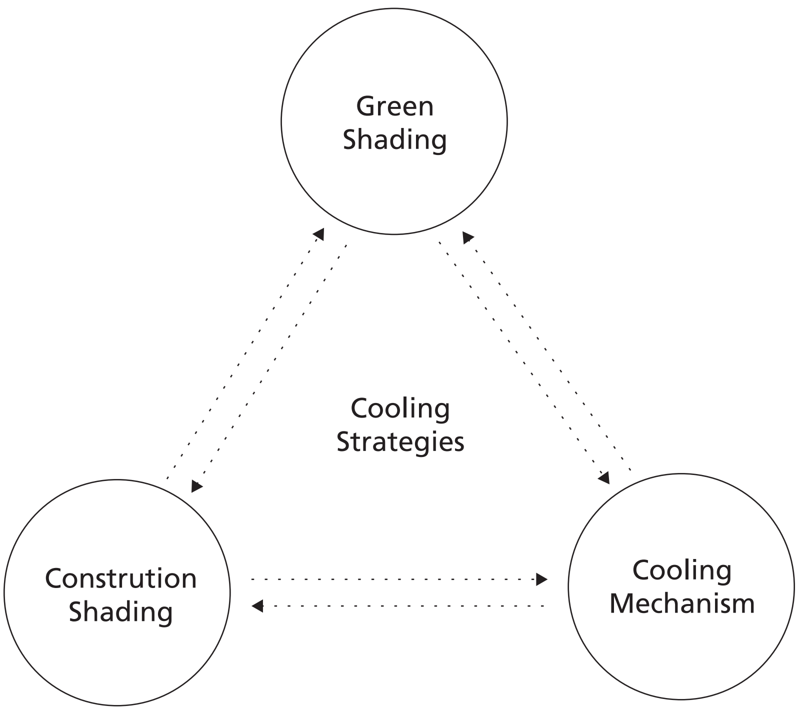
VI THE URBAN COOLING STRATEGY

Based on the simulation results, Chapter Six proposes three human-oriented sustainable cooling strategies for Helsinki. A web-based platform is designed as the carrier of strategies for citizens and government.

Outdoor thermal comfort is essential for city well-being. Joint holding activities in public space or individually walking along with the street needs a delightful microclimate as the undertaking's condition. It is the designer's responsibility to create such suitable spaces. Formerly urban planners and architects may use intuition or design-based experience to make conclusions. With the computational assistance integrated into the workflow, design can more accurately intervene in urban space to make a difference.

It is easy to foresee that heatwaves in Finland will become more frequent in the future. Various outdoor spaces will become hazardous for citizens in these cases. For prospects of promoting outdoor quality and humans well-being, multiple urban cooling strategies are conceived.

The chapter put out three kinds of cooling strategies for Helsinki to pursue a more resilient city. These strategies compensate for each other’s defects with their strong points. Eventually, strategies combined in multiple forms can be applied to diverse urban spaces, making immense impacts on citizens’ living spaces and lifestyles.



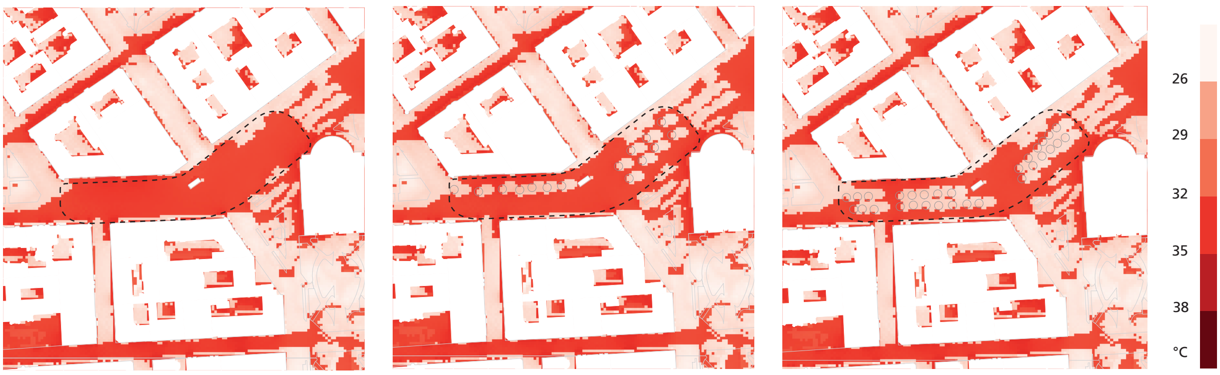
6.1 Three strategies compensate each other.

Green shading Helsinki

Shading is the most intuitive way to cool down the pedestrian level thermal sensation, and trees have noticeable effects. Previous researchs and simulations have illustrated that different land coverings possess limited impacts on outdoor thermal comfort, whereas planting trees is a more efficient way. Hence, it was wishful to achieve a comfortable thermal environment by replacing with grass in formerly design works. In Helsinki, there are many no tree-covered outer spaces. These areas usually are under high risks in heatwave occasions. The situation would be significantly improved if trees shade these places. According to the different functions of outdoor spaces, experiments are taken to simulate woody plants' effects.

The simulation areas are between 8,000 to 10,000 m2, identified as the hot zone in the previous simulation. The trees are deciduous, with 8 meters in diameters and 15 meters in height (5 meters trunk zone). As a result, single arbor with an approximate 50 m2 canopy can produce approximately 84 m2 shaded areas at 1 pm.

30 = 400m Comfort Sidewalk

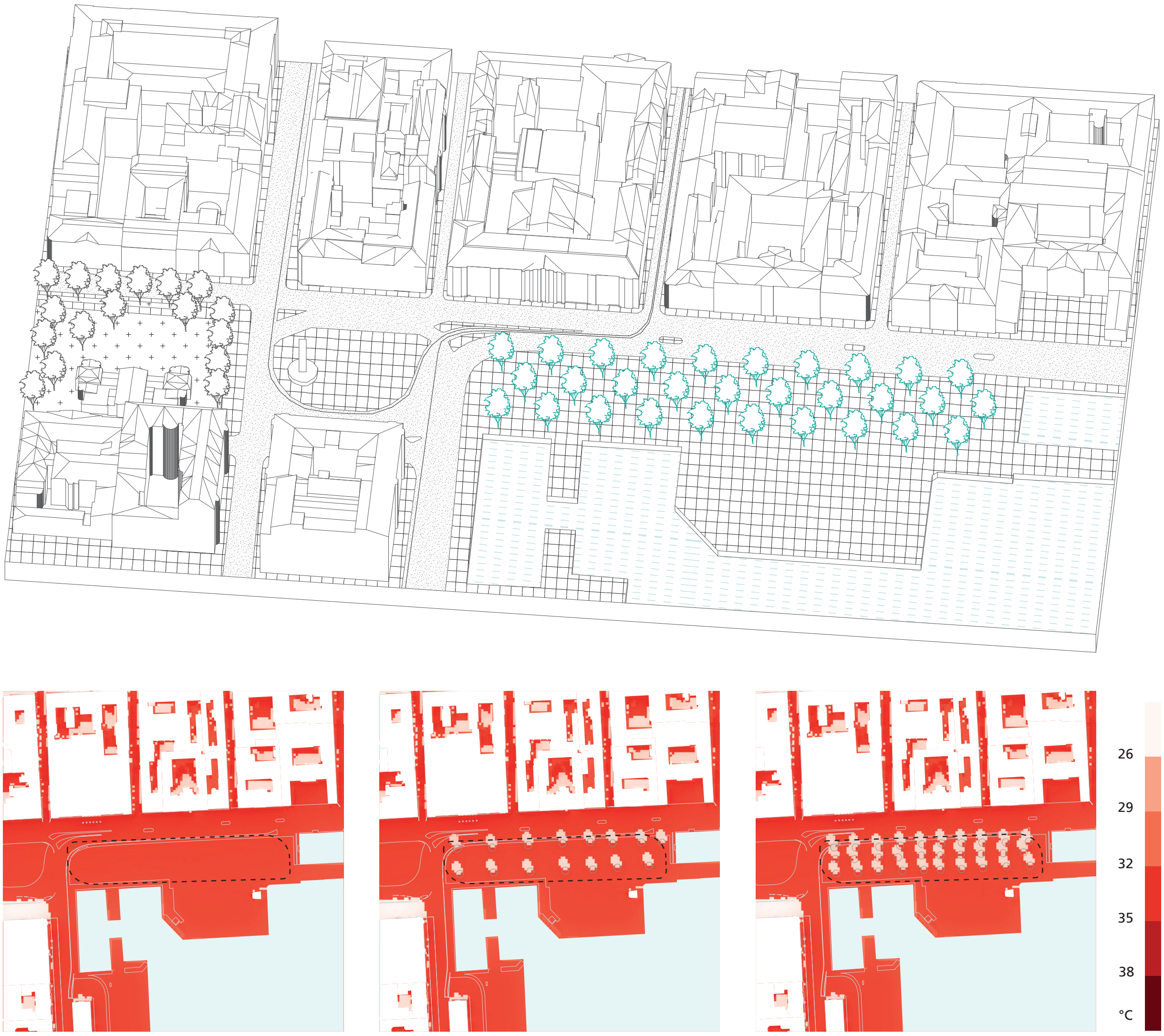


6.2 Simulating the impacts of 15 & 30 more trees in Erottajankatu.

1. Greener streets

Streets, as the most frequently used outdoor space, afford people's daily travel and commuting. Erottajankatu is a part of the main street connecting the city center to the outside. Erottajankatu currently has five lanes and two light rail tracks without much greening. In other words, the sidewalks are entirely exposed to the sun. If combing the parking lanes with greenery, 30 arbors can fully cover the 200 meters long sidewalks on both sides, giving citizens shaded streets in summer. However, streets need changes to achieve this, considering the existing structure.

30 = 9,000m² Cozy Bazaar

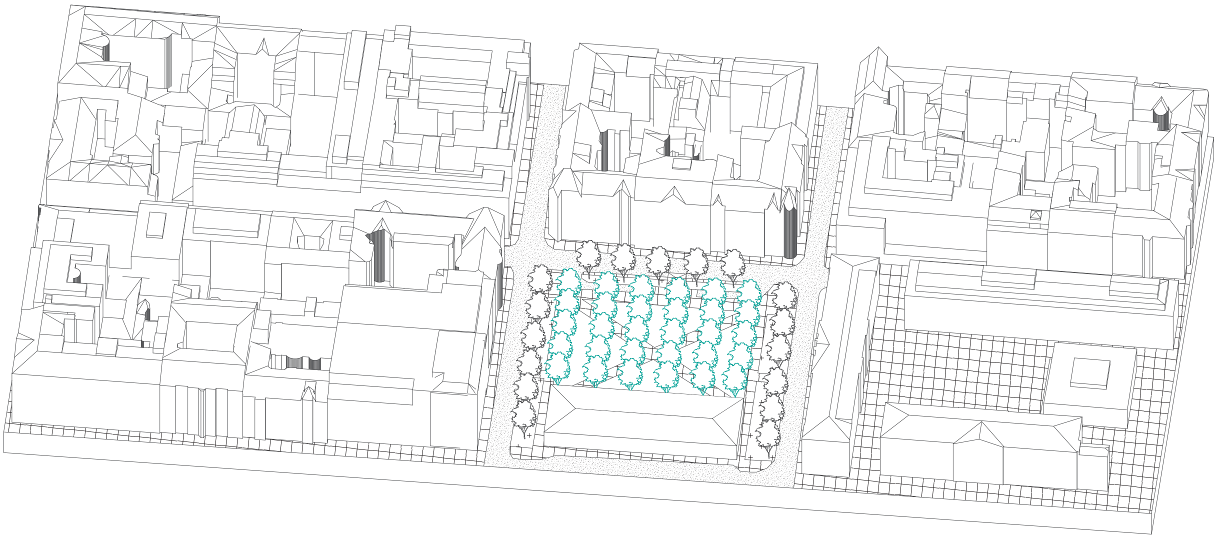


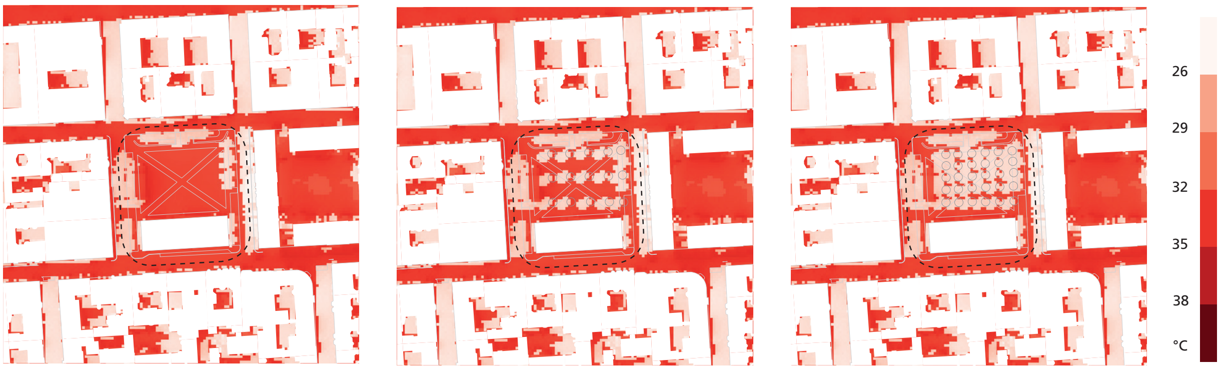
6.3 Simulating the impact of 15 & 30 more trees in Kauppatori.

2. Greener markets

Market places have become cultural assets of the city. Shopping at a local market is a daily behavior for inhabitants and a wonderful experience for tourists. The simulation illustrates that thirty deciduous trees can protect half of 9000 m2 Kauppatori from exposure to solar radiation. Trees can be well interspersed between the stalls to give residents and visitors a pleasant bazaar experience.

30 = 3,000m^2 Cool Square





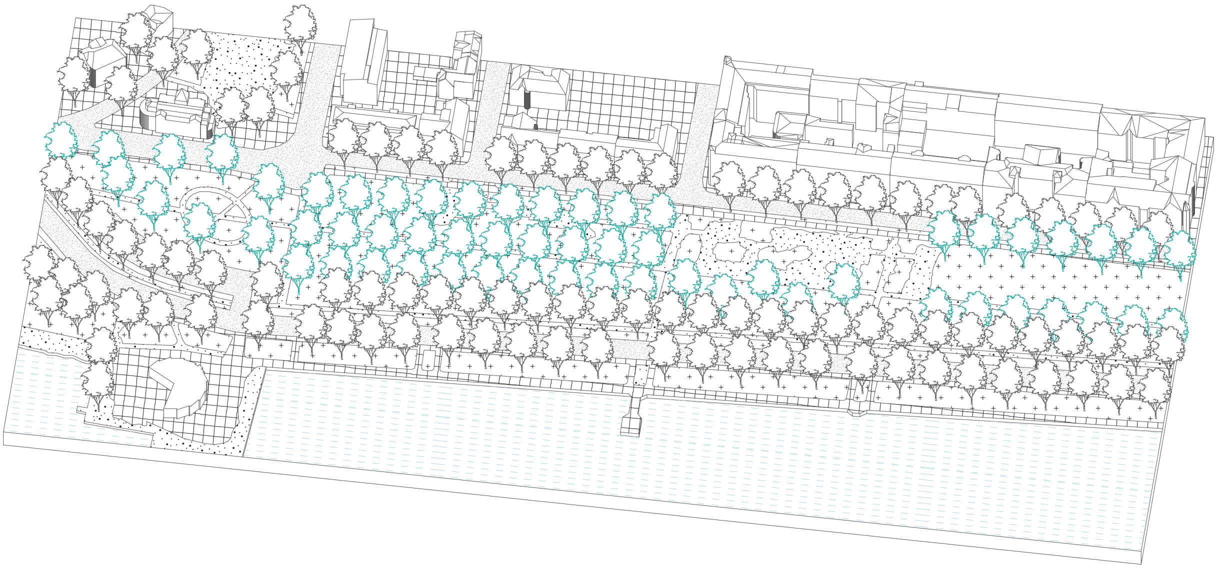
6.4 Simulating the impact of 15 & 30 more trees in Kasarmitori.

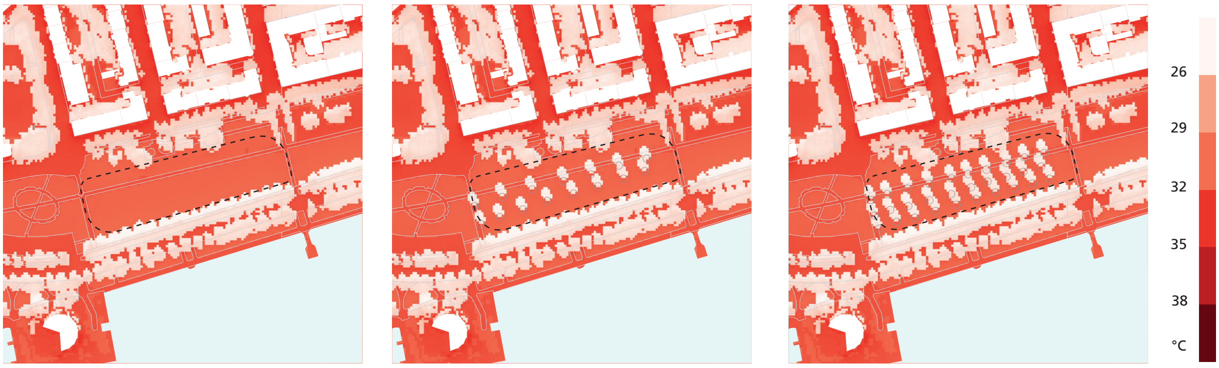
3. Greener squares

The square embodies the distinctive features of a city's architecture, culture, crowds, and activities. Kasarmitori, as an example, represents the characteristics of Helsinki squares, where only a few sculptures extruded above the impermeable pavings. People can enjoy a broad vision, whereas feeling sweltering in summer.

Thirty trees can wholly shade the Kasarmitori via software computing. More greenery will bring a new appearance to squares. Organized arbors can also contribute to highlighting the culture.

30 = $10{,}000m^2$ Charming Park





6.5 Simulating the impact of 15 and 30 more trees in Fredrik Stjernvallin Puisto.

4. Greener park

People favor parks, especially during holidays. However, large lawns dominate the covering of artificial park built in Helsinki. Recreating in these parks in heat events may pose specific health threats.

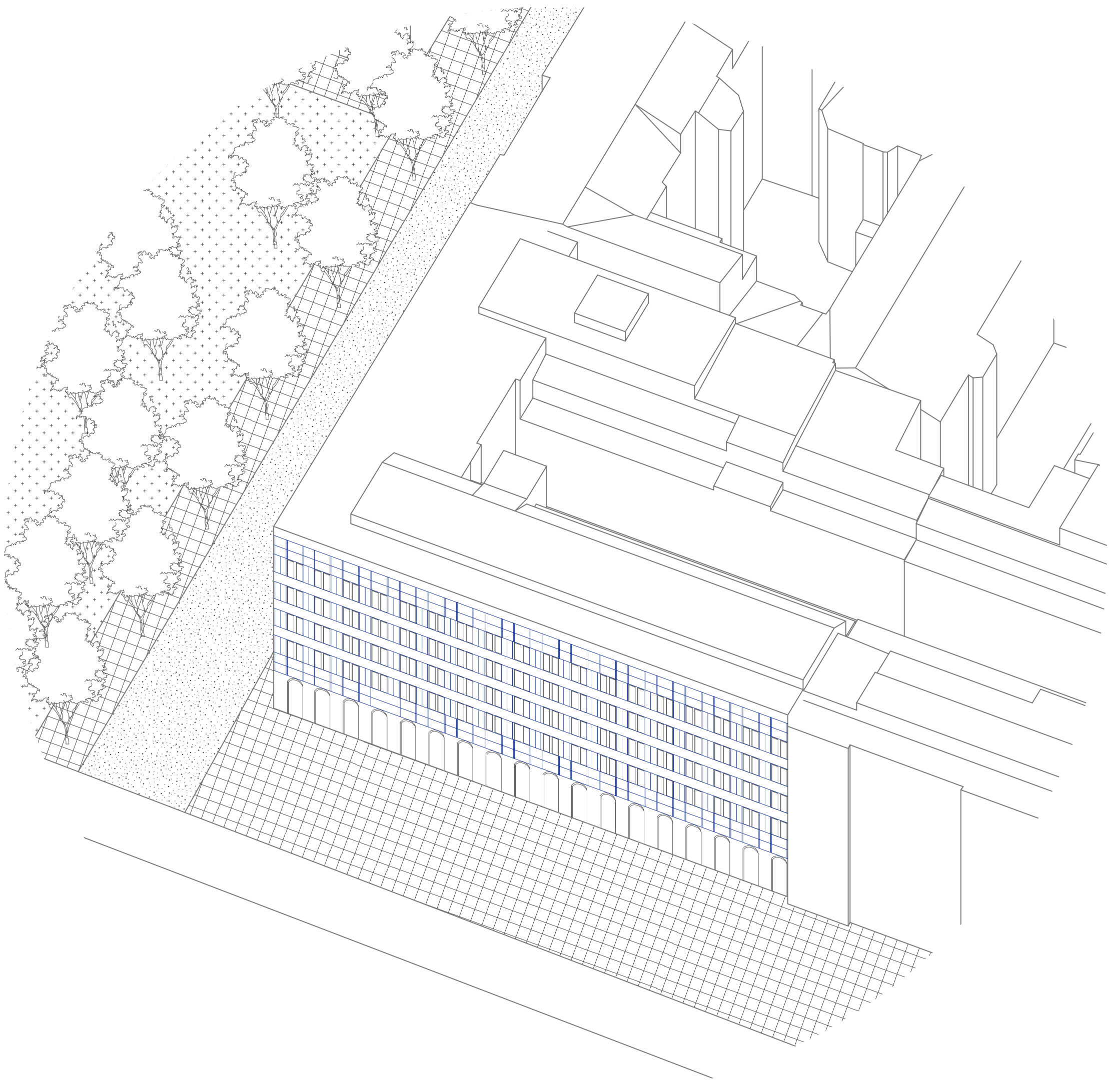
As a park located in the south of Helsinki, citizens like to go to Fredrik Stjernvallin Puisto for a picnic or skateboarding in summer. Thirty trees can shade a considerable part of the park and make it more diverse. Residents will have a better environment for picnic and recreation. Moreover, those who come to have outdoor sports or interact with children can still enjoy a broad vision.

Intelligent façades for pedestrians

Façade, as the complicated interface protecting or regulating building interior from the fluctuations of the outsic
intelligent facades can be divided into five categories: double-skin façade, double-glazed façade, ventilated faça
comfort. Furthermore, for those facades which optimize outdoor microenvironment through covering specific m
on the thermal environment because diverse pavements have been proved not as efficient as shelter shading. Th

Large public buildings such as Oodi or Central Railway Station are equipped with empty squares without any she
shade the adjacent pedestrians. The dynamic skins consist of many “shutters.” These “shutters” lie along the fa
ed with sensors that can consecutively measure the volume of heat and light and control the “shutters” mechan

The dynamic facades can extend the shadow range of the architecture in summer and provide delightful walking

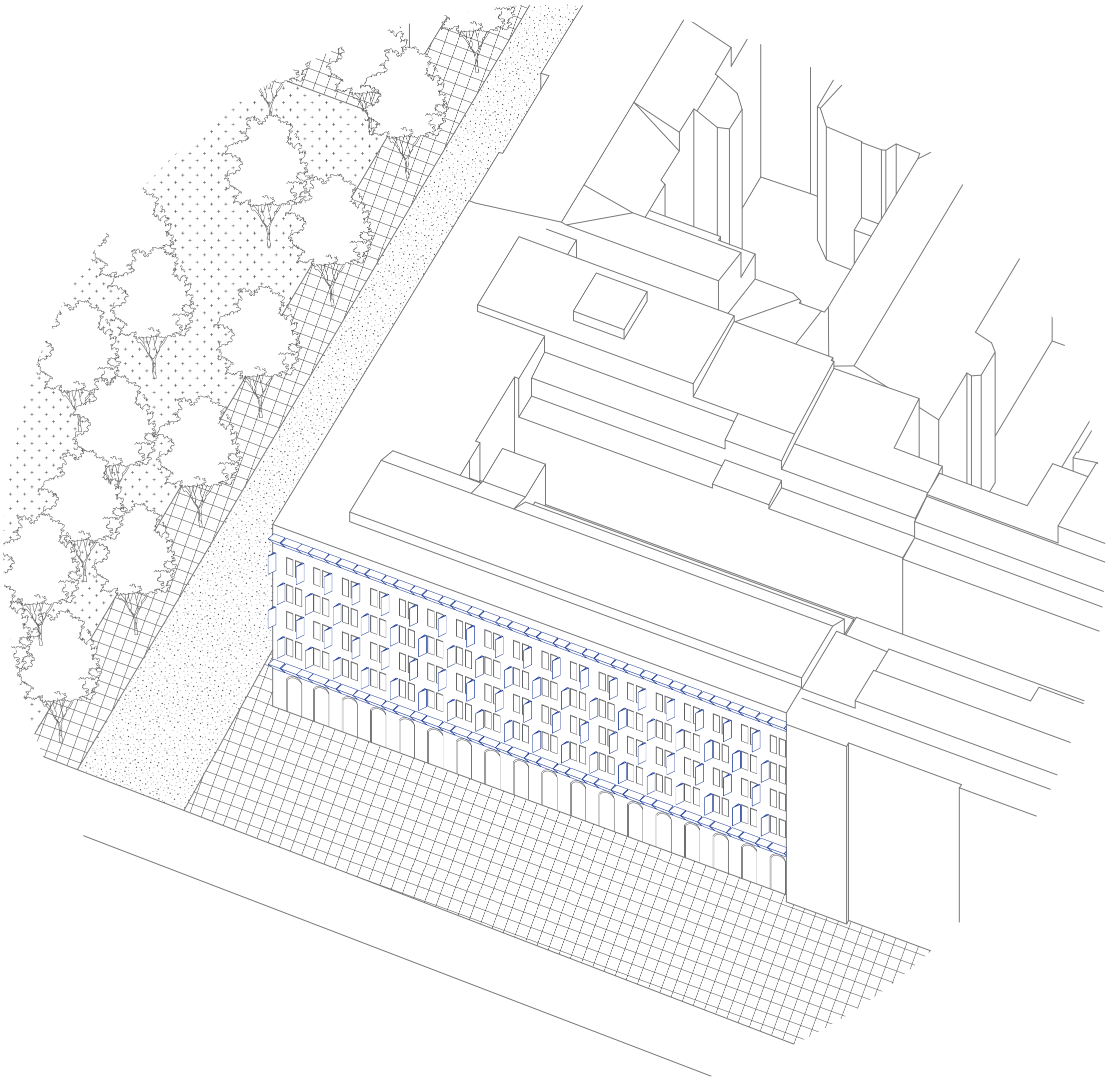


6.6 Kenetic facades in usual state.

de environment, has an underlying impact on the surrounding microclimate. (S.M. Hosseini, 2019) Currently, de, kinetic façade, and solar façade. (M.S. Ahmed, 2015) However, most facades are focusing on indoor thermal aterials to absorb solar radiation or altering the angle of the surface with the sun, it may cause limited impacts hus, intelligent facades here will concentrate on possible kinetic ones of enlarging the shadows.

elters. Moreover, many roads are too narrow in the city center to get trees planted so that kinetic facades help çade as usual, while they protrude from the façade when the heatwave comes. The intelligent façade is regulat- nically in different conditions.

g space for pedestrians.

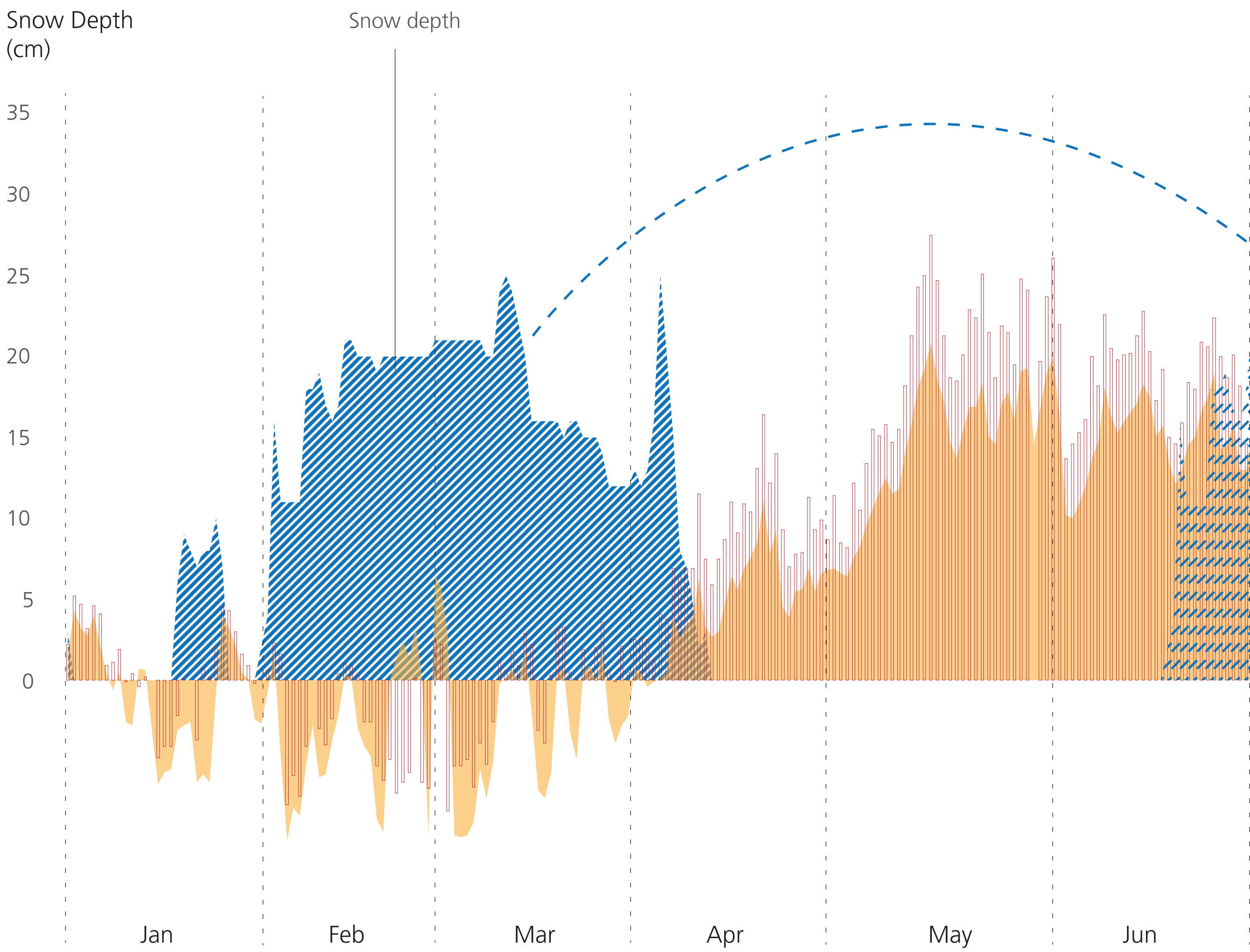


6.7 Kenetic facades in summer.

The “Snow House“

For many areas such as town square, planting trees is not the best decision because it sacrifices the broad vision
ing in high-temperature weather.

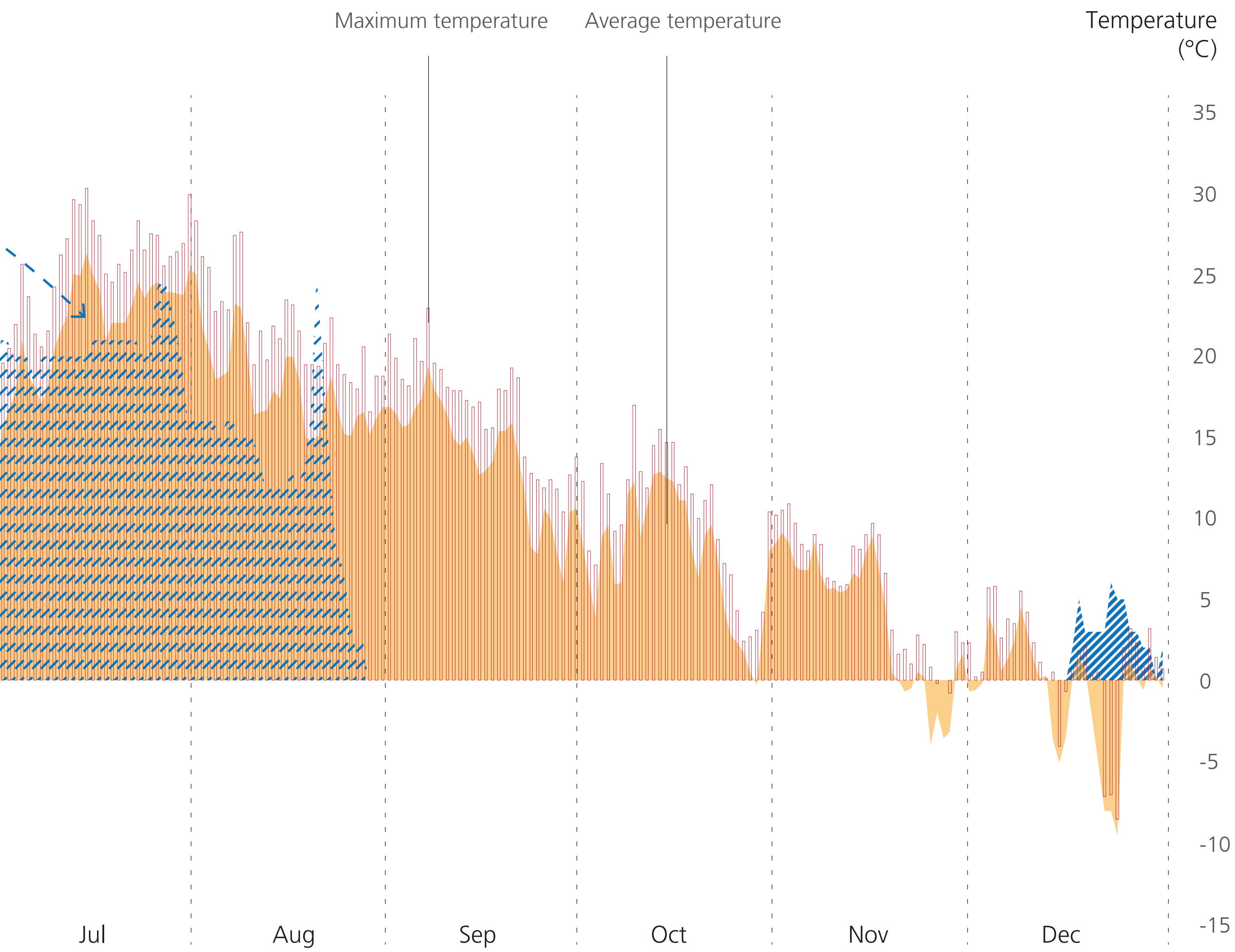
Hence, the thesis proposes a new cooling mechanism. The mechanism, on the contrary, is an ecological respons
there will be 2 °C temperature ascending in the winter of 2050, extreme climate such as intense snowfall (> 10
burden on the environment. Meanwhile, it can effectively deal with the problem of snow cleaning in Helsinki.



6.8 Diagram to show the snow storage for summer.

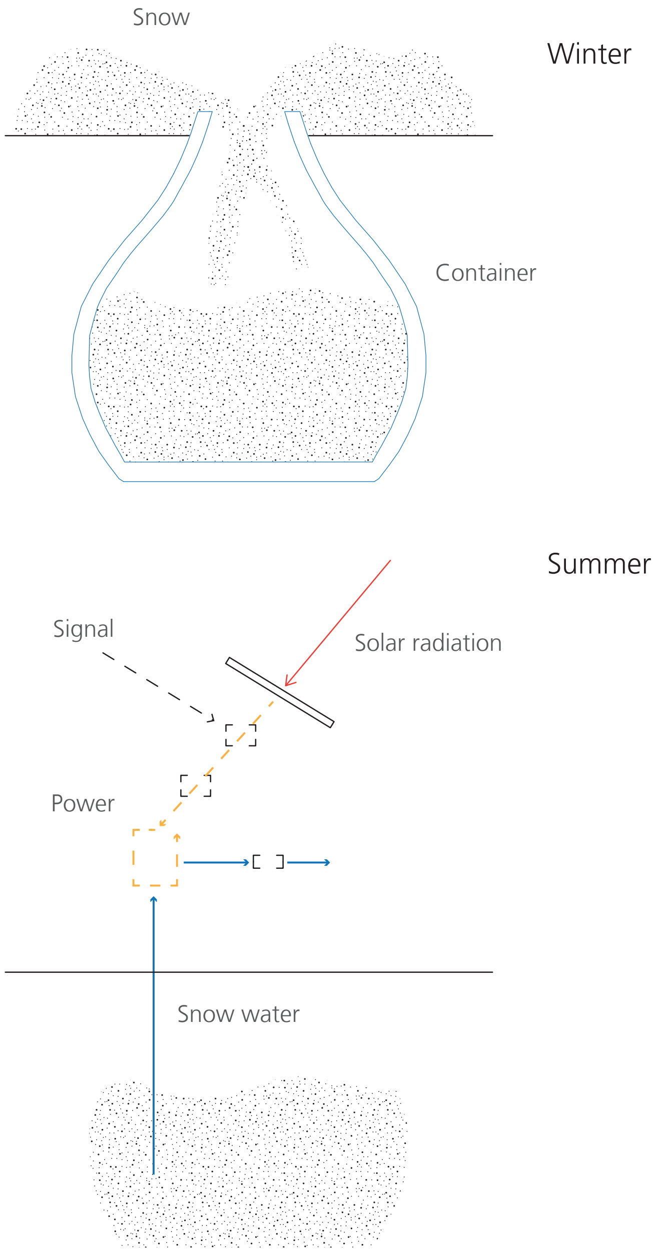
s or crowd gathering functions. Therefore, research proposes a mechanical device that enables public area cool-

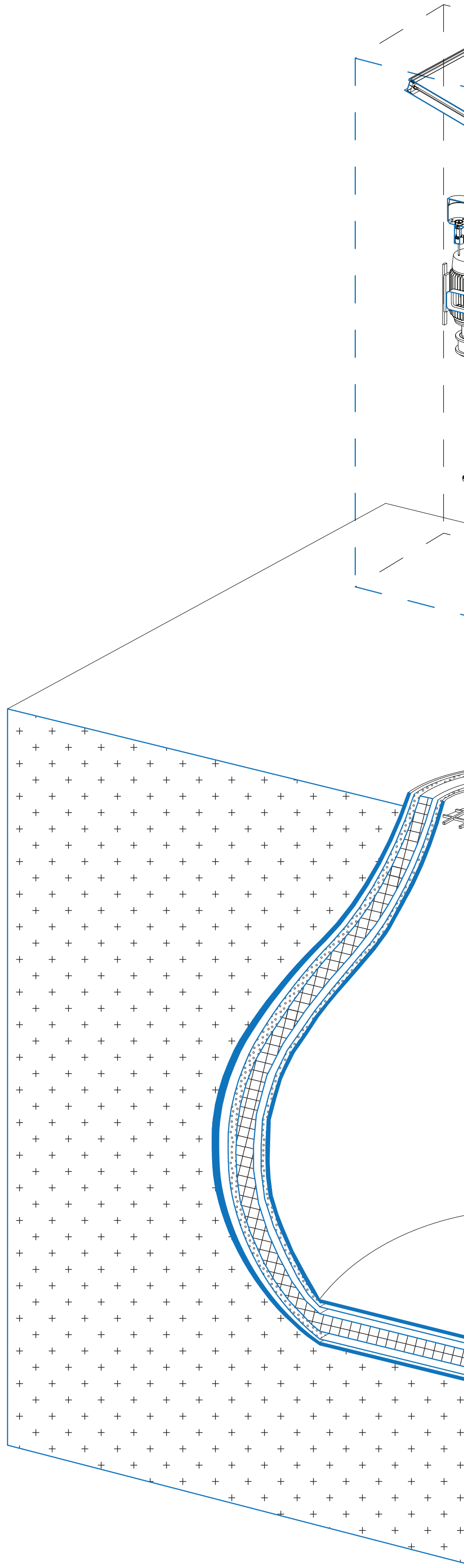
e to the scorching climate through storing winter snow and releasing it as cold air during heatwaves. Although cm/day) will be more common. (Finnish Meteorological Institute, 2019) This cooling method will not cause any



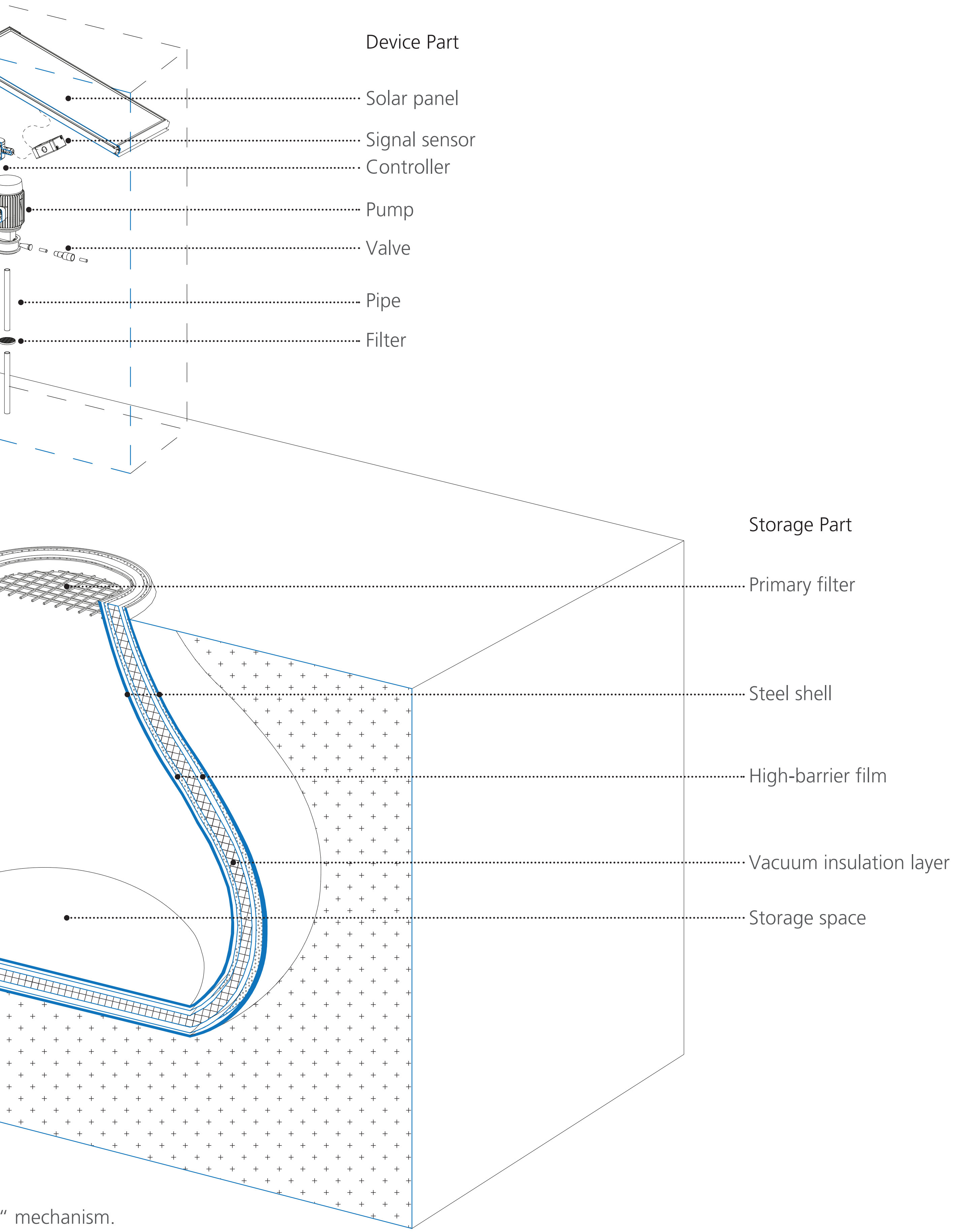
1. Abstract principle

This mechanism consists of the underground storage part and the above-ground device part. In the winter, people can put accumulated snow into steel space through coarse filtering. The insulation materials ensure the long time storage of snow. When the heat-wave comes, the sensor will receive signals and activate the pump to release the snow water outside. The valve can adjust the speed according to the temperature. Solar panels charge the entire device, which will not burden the environment.





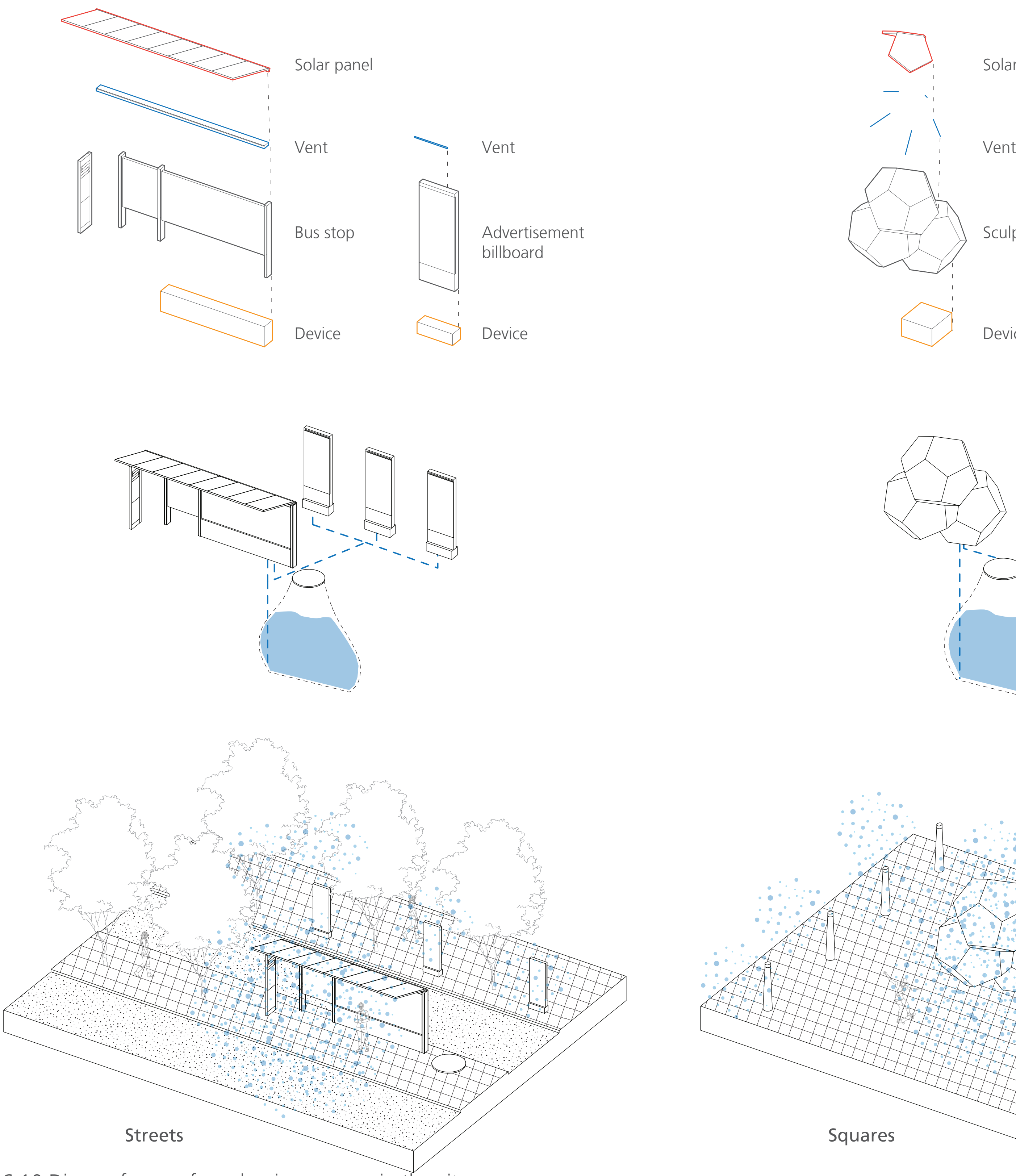
6.9 Abstract principles of "snow house


Device Part
Solar panel
Signal sensor
Controller
Pump
Valve
Pipe
Filter
Storage Part
Primary filter
Steel shell
High-barrier film
Vacuum insulation layer
Storage space

" mechanism.

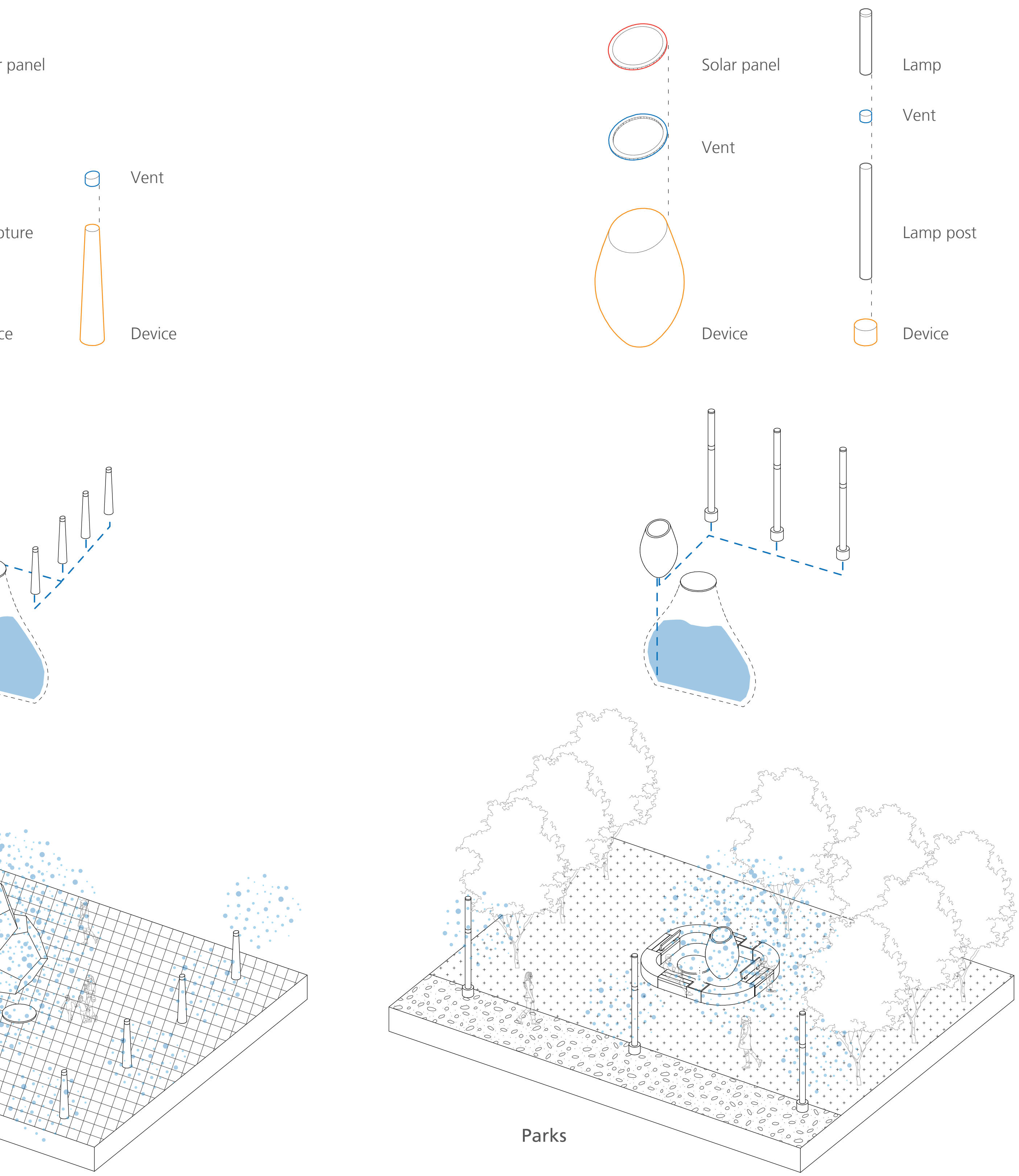
2. Conceivable adaptation in urban space

"Snow house" varies in different functions of urban space. Usually used as ordinary urban furniture, the mecha



6.10 Diverse forms of mechanism appear in the city.

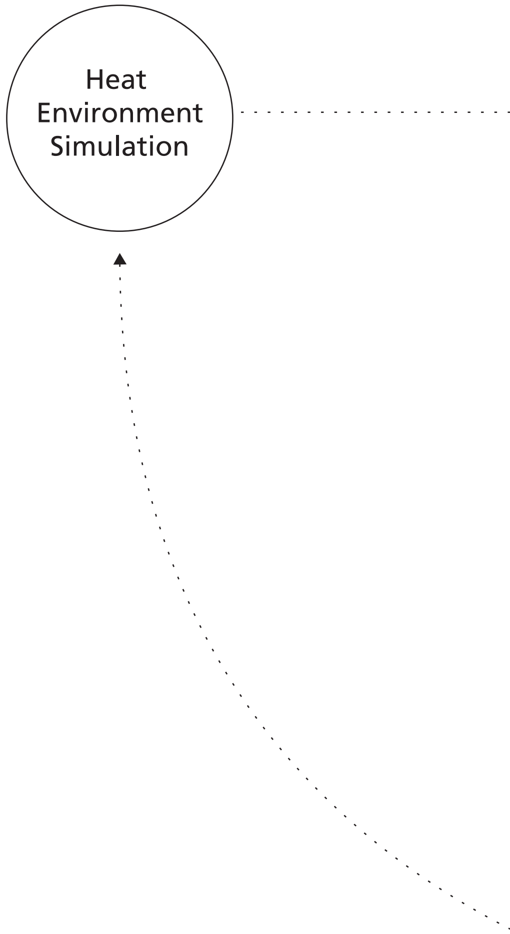
nism will be activated to bring fresh coolness to the residents when the heat event comes.

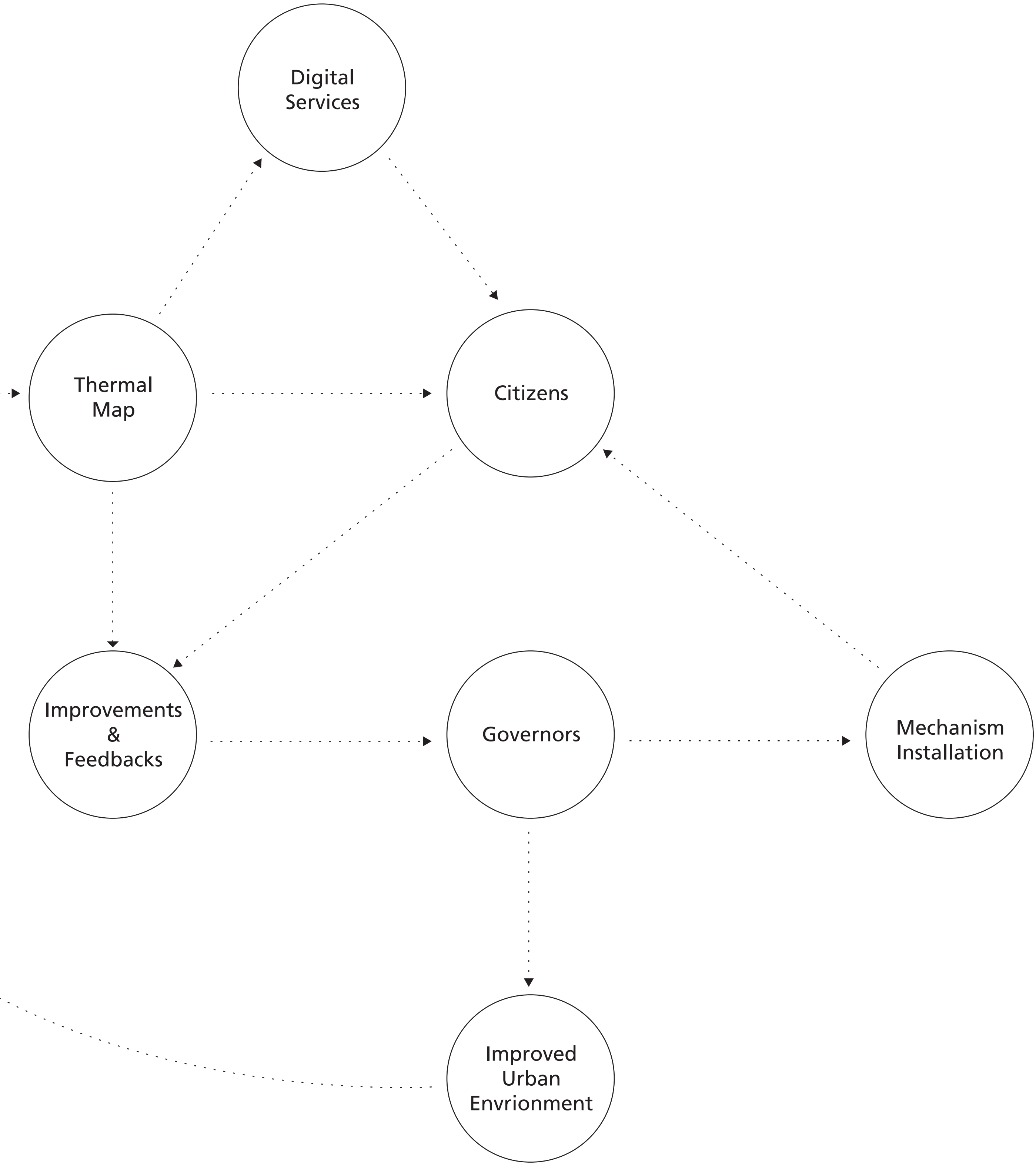


Interacting with residents and urban managers

As a carrier of thermal environment simulations and designs, the designed web-based platform interacts with residents and urban managers in a more intuitive and visual method. Through this platform, residents can participate in these actions to ameliorate the thermal environment in Helsinki and sense the city's improvements.

The designed application, as the output of the platform, consists of four primary services: Exploration of the Urban Heat Map, Feedback from Citizens, Outdoor Activity Guidance, and Integration of Snow House Mechanism in the Application.





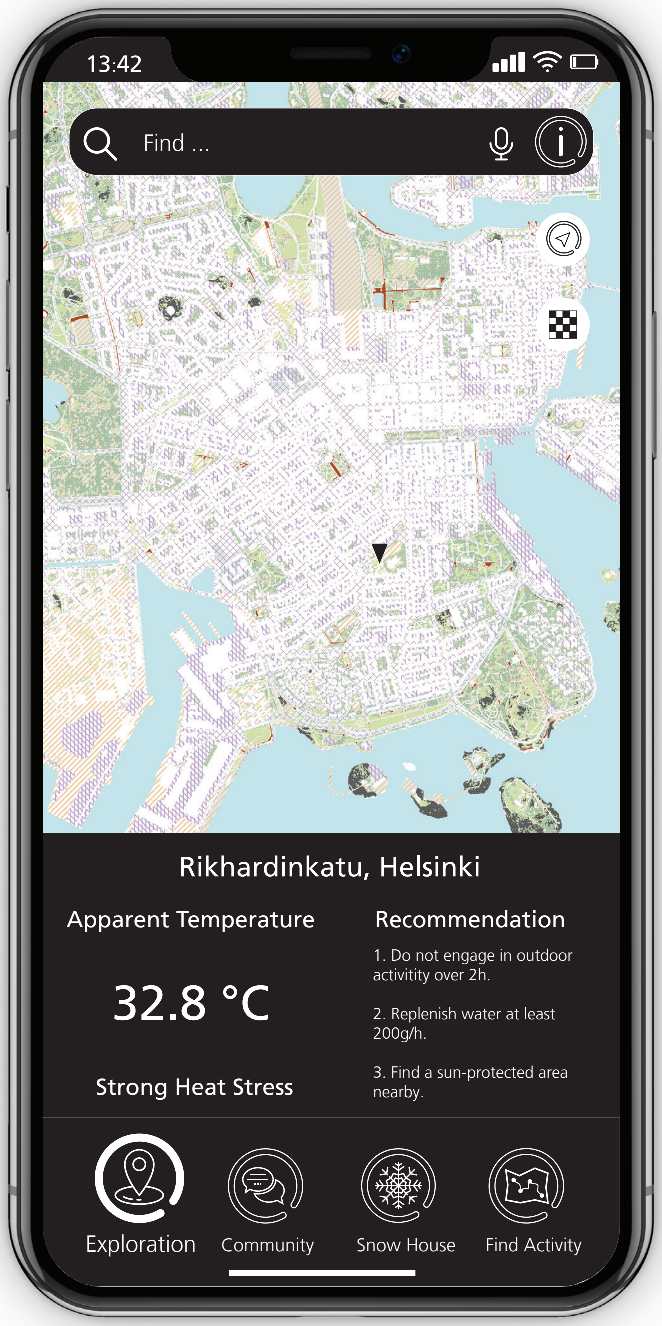
6.11 How the platform interacts with citizens and governors to make city more resilient.

1. Exploration of the Urban Heat Map

The Exploration part is the real-time urban thermal map, where citizens can access site-specific, live data on Helsinki's thermal condition. The users are automatically located according to their GPS position and will receive the precise heat stress data of their place. What is more, the application provides users outdoor activity recommendations according to different heat stress.

Thermal map

Standard mode



6.12 The real-time thermal map of Helsinki.

Heat mode


13:42
Find ...
Search bar
Information
Locate yourself
Switch Heat/Standard mode
Thermal map
Rikhardinkatu, Helsinki
Apparent Temperature
Recommendation
Suggestions
1. Do not engage in outdoor activitity over 2h.
32.8 °C
Thermal sense
2. Replenish water at least 200g/h.
Strong Heat Stress
3. Find a sun-protected area nearby.
Exploration
Community
Snow House
Find Activity

2. Feedback from Citizens

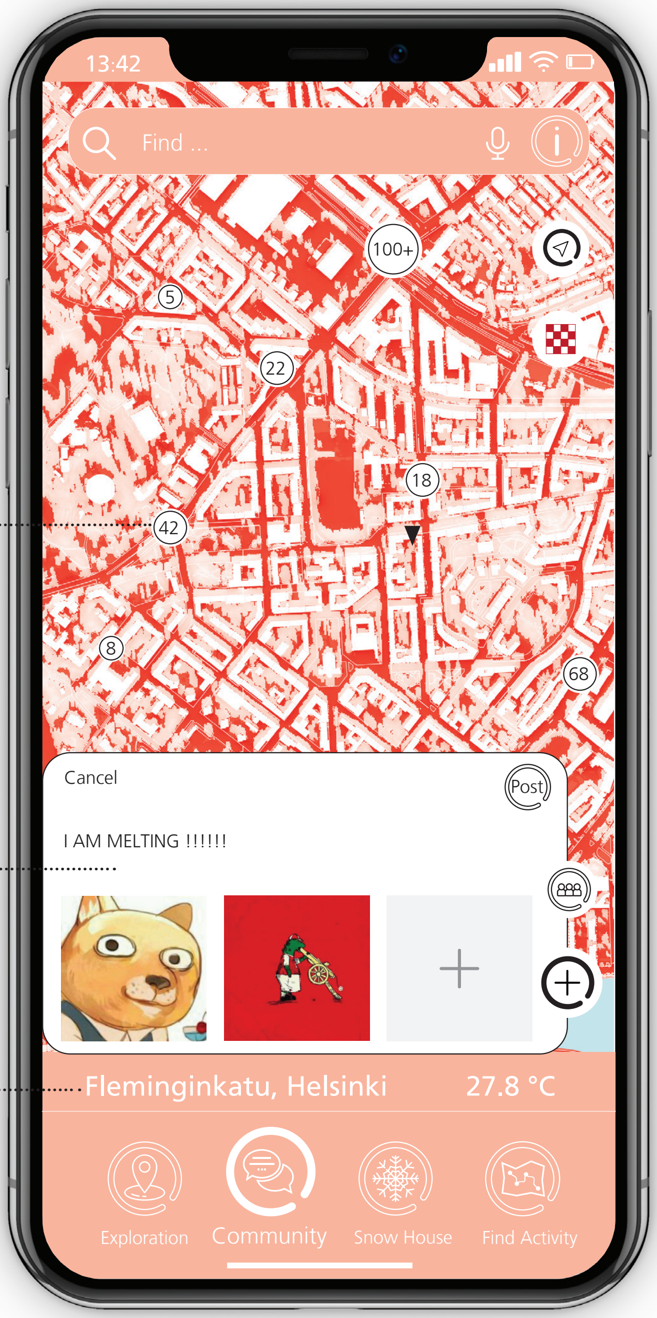
The Community function allows the public decision-makers to “listen” to the citizens’ voice in a more focused and site-specific manner. According to the collected data, clear actions could follow as a second step. This tool would prevent authorities from investing in time-intensive research. Instead, concrete measures, such as planting trees, building intelligent facades, and installing cooling mechanisms, could be taken.

Share your feelings

Number of opinions in this area

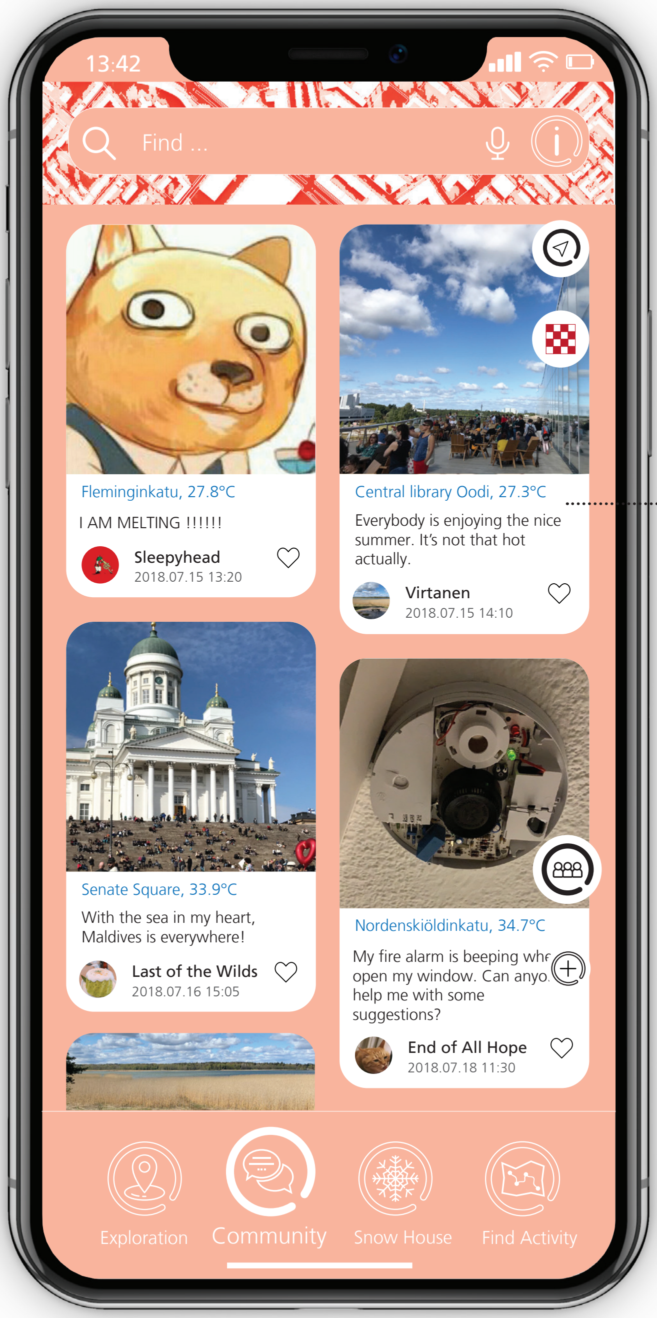
Post your Feelings!

Your location



6.13 The experiences&opinions of citizens.

Experiences&opinions from citizens

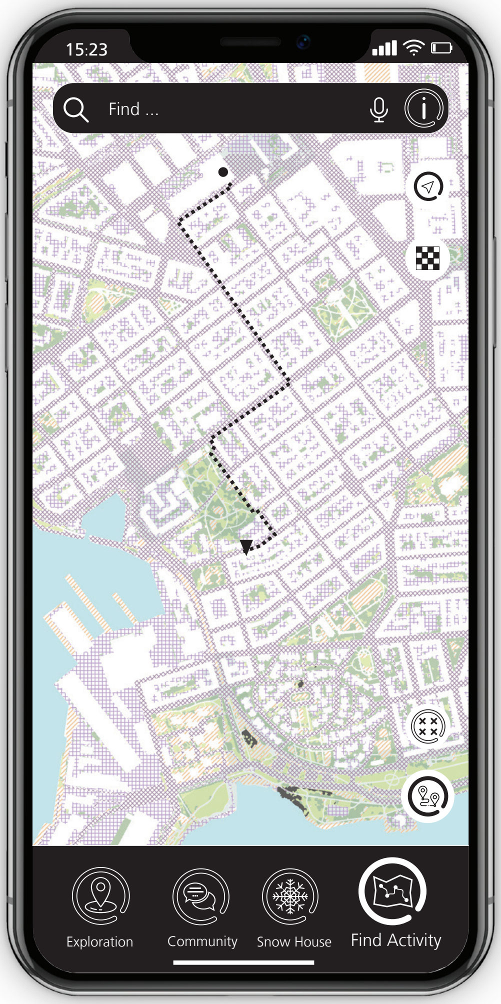


Feelings from nearby

3.Outdoor Activity Guidance

There are many dangers when people carry out outdoor activities in heatwaves, especially for the elderly. Therefore, the application can provide users with a more suitable and site-specific proposal for outdoor activities.

Finding a pleasant commuting way



Find a pleasant way for jogging

6.14 Outdoor activity guidance from application.

Places to be avoided for elderly

Best places for outdoor activity

4. Integration of Snow House Mechanism in the Application

When the mechanisms settle, they can help to cool down the nearby area. There are two modes of operation. The mechanisms existing in broad public space such as parks and squares activate automatically. In heatwaves, the application continuously sends the apparent temperature to the mechanisms. The mechanism will activate when the received temperature is higher than 28 degrees.

For places with little occupation of people, the mechanism can be controlled through the application. Inhabitants who stay in these spaces can turn on the mechanism nearby until the connection breaks.

Space with many people (park)

If the place is > 28 °C AT

Send signal

Mechanism

Emit cold air

Space with few people (bus stop)

People feel sweltering

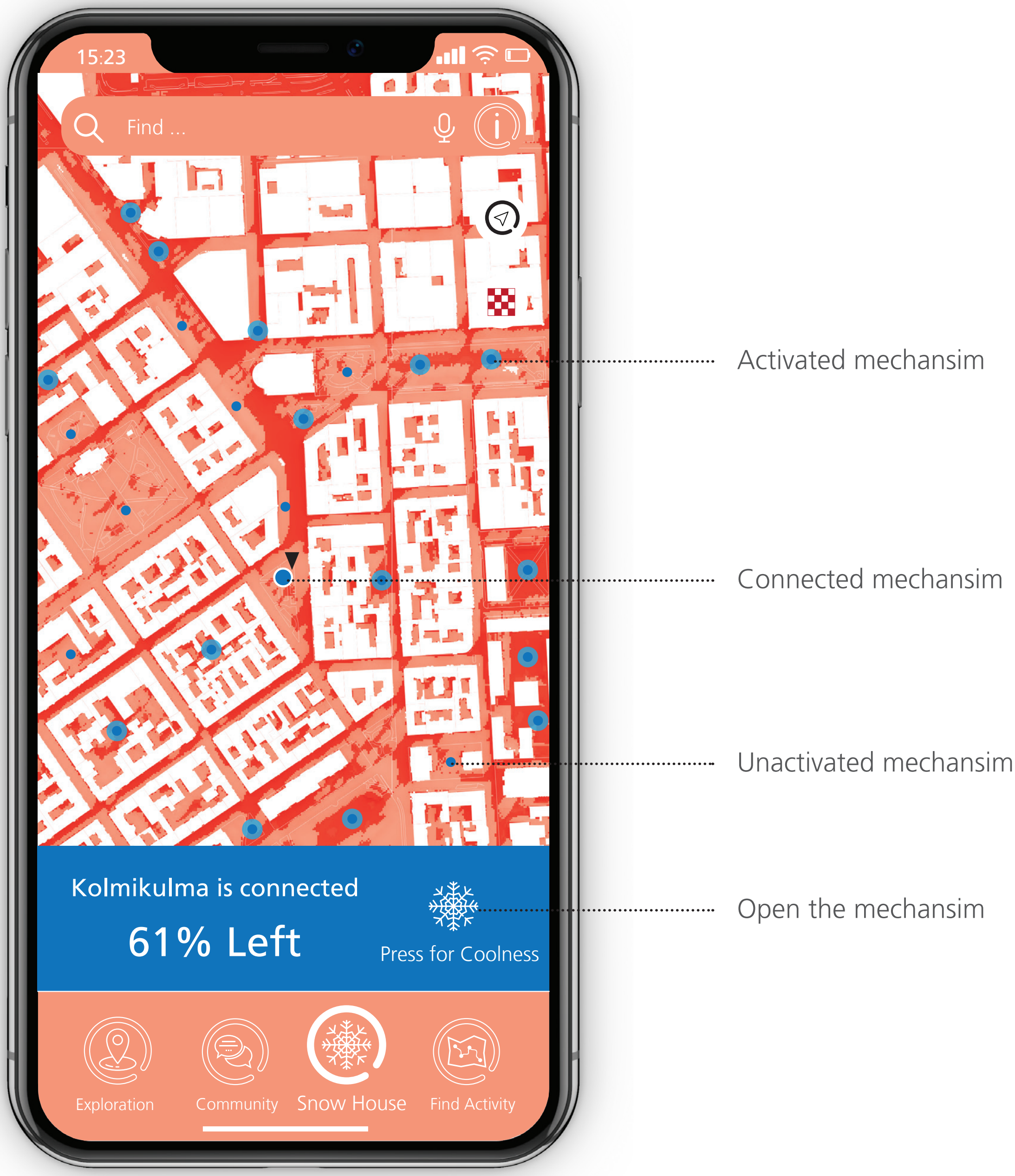
Click on APP

Mechanism

Emit cold air

6.15 Operation function of mechanism.

Machanism for cooling down



6.16 Mechanism control panel.

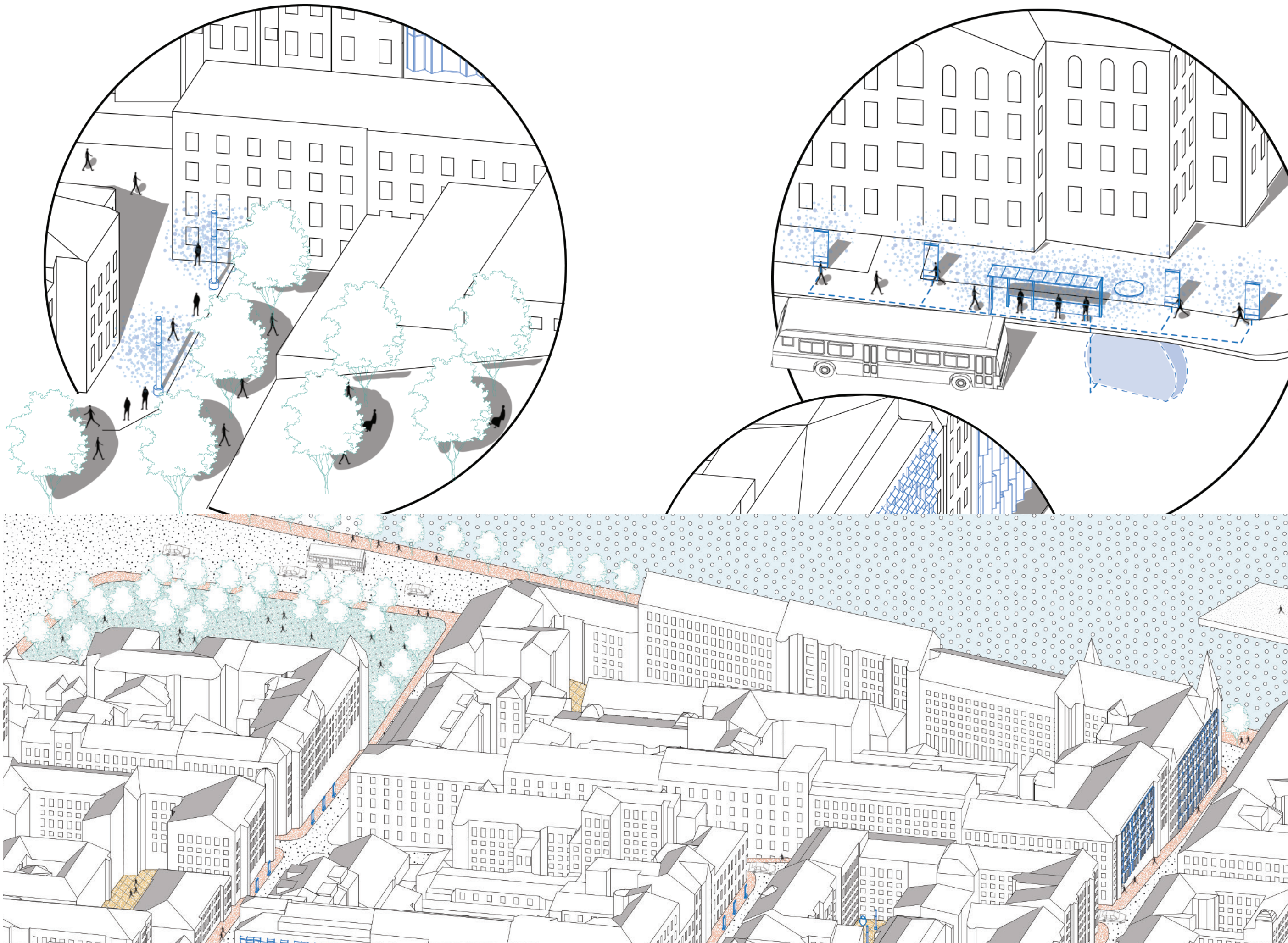
VII THE URBAN SCENARIO

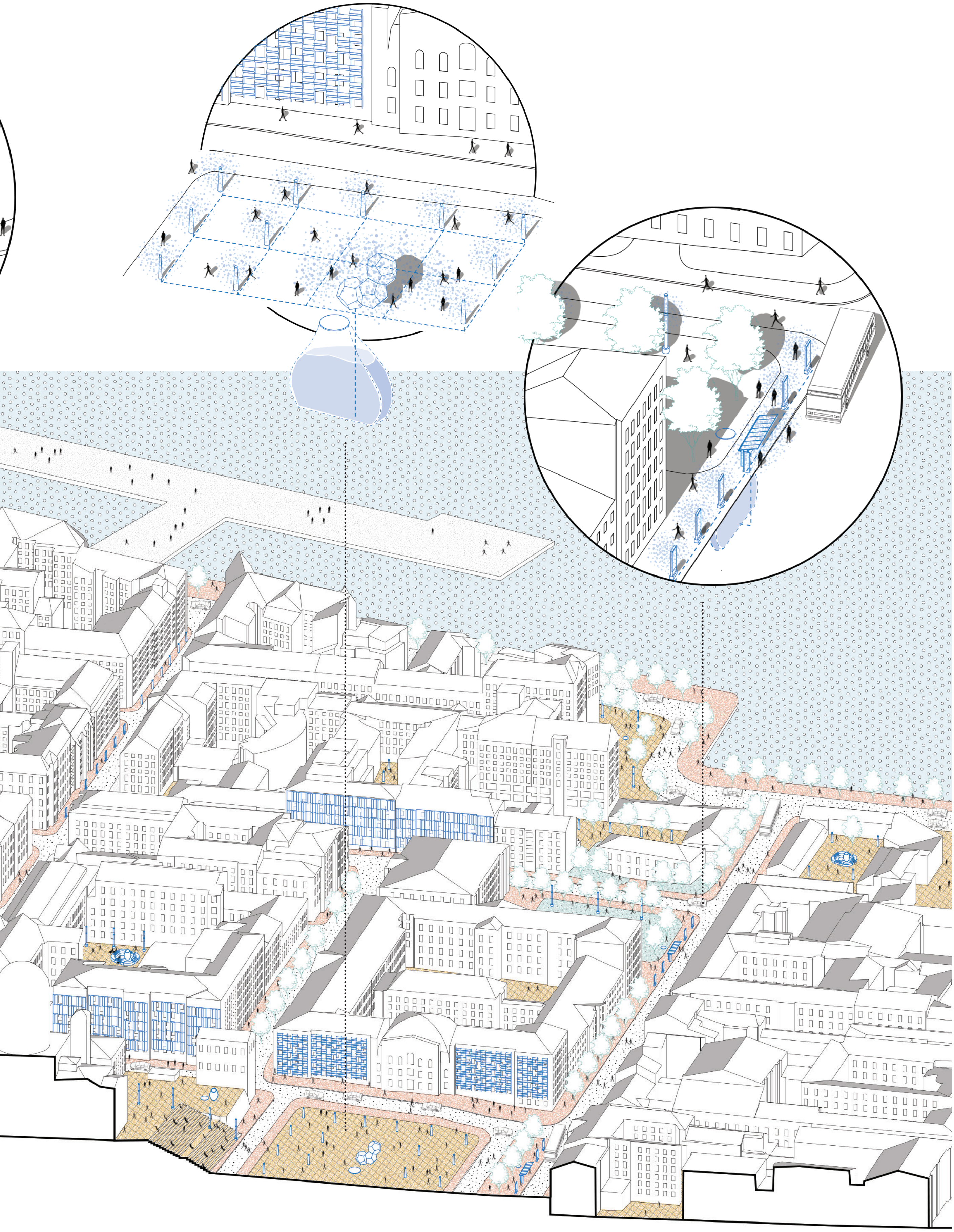
Towards Helsinki Sustainable Development Goals, Chapter Seven envisions the scenario in which the strategies are implemented in the city and its impact on residents.

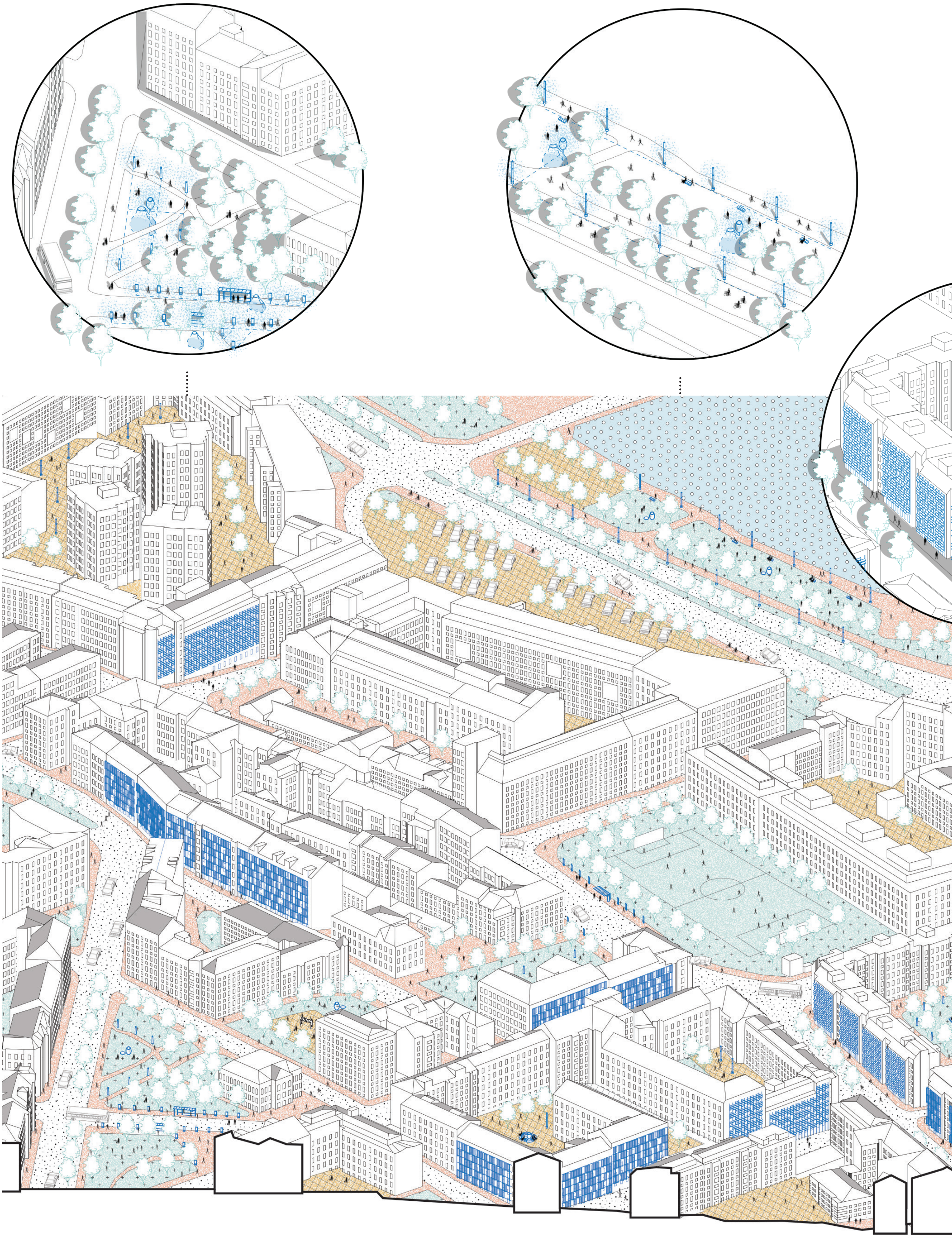
There is no way to go back. The City of Helsinki needs to research solutions to deal with the increasing heat.

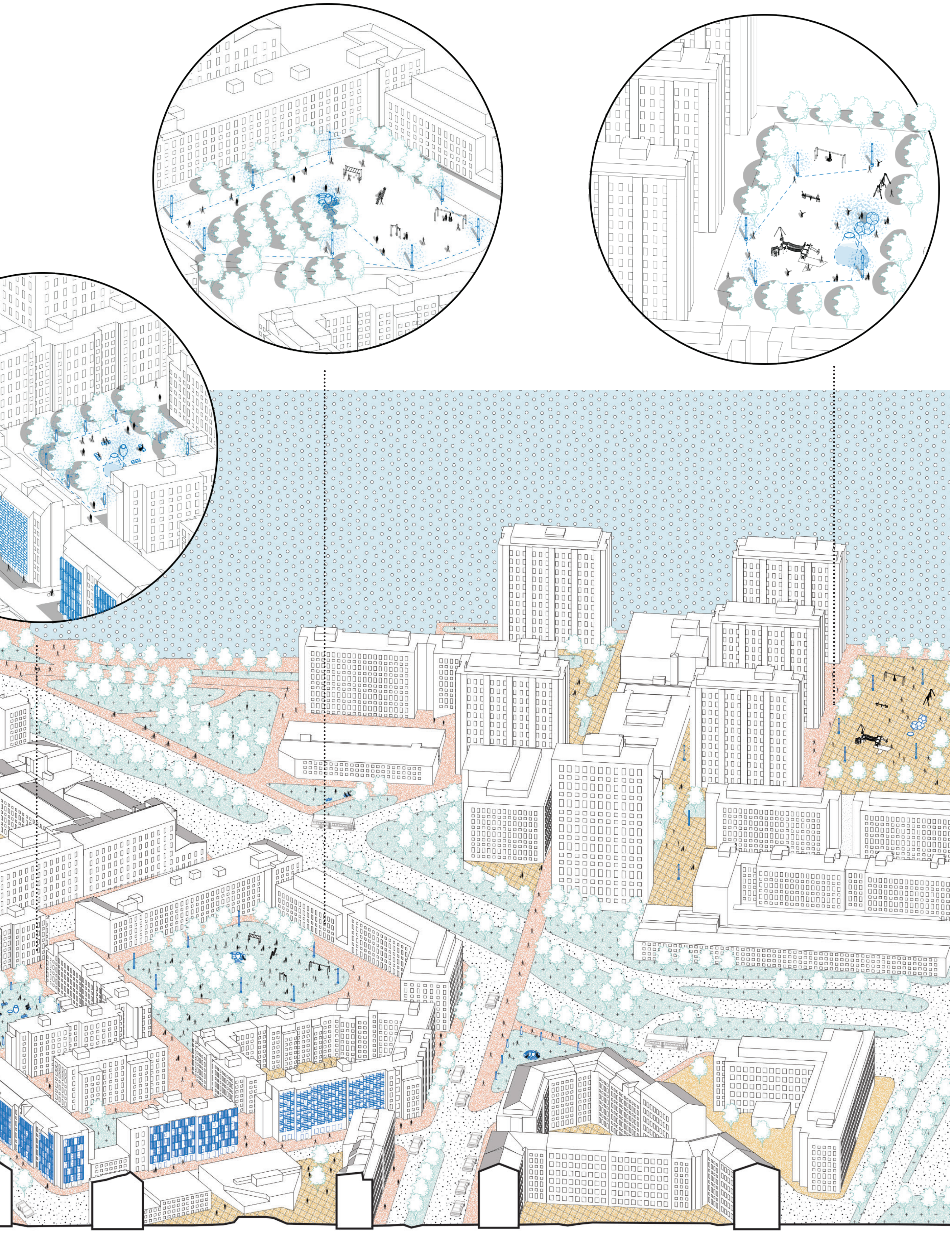
In order to cope with future extreme climates, cooling strategies need to be designed according to the site-specific challenges to make the City of Helsinki a resilient place with a high outdoor quality of stay.

According to the Helsinki Sustainable Development Goals (City of Helsinki, 2019), Helsinki is transforming into the most functional city with implementing sustainable development responsibility locally. Towards this objective, the implemented interventions impact Helsinki and its inhabitants. On the one hand, the design works fill the existing gap in urban services and infrastructure in the forthcoming extreme climate. On the other hand, participating in the thermal environment confrontation will popularize sustainable awareness among urban residents. Moreover, the characteristics of sustainable development and government-resident interaction will make Helsinki the city unique.









Building a future vision and strengthen urban resilience

The strategic objective is to bring the city a more sustainable future in the context of global climate extremes. Under the future vision, the urban cooling strategies will enrich the outdoor lifestyle of citizens in summer. The implemented strategies will also change the city's appearance and lead Helsinki more adaptable to heatwave events. To realize the future vision, everyone needs to participate in developing and promoting Helsinki.

7.3 The scenario of the Oodi library where people enjoy the summer pleasantly.

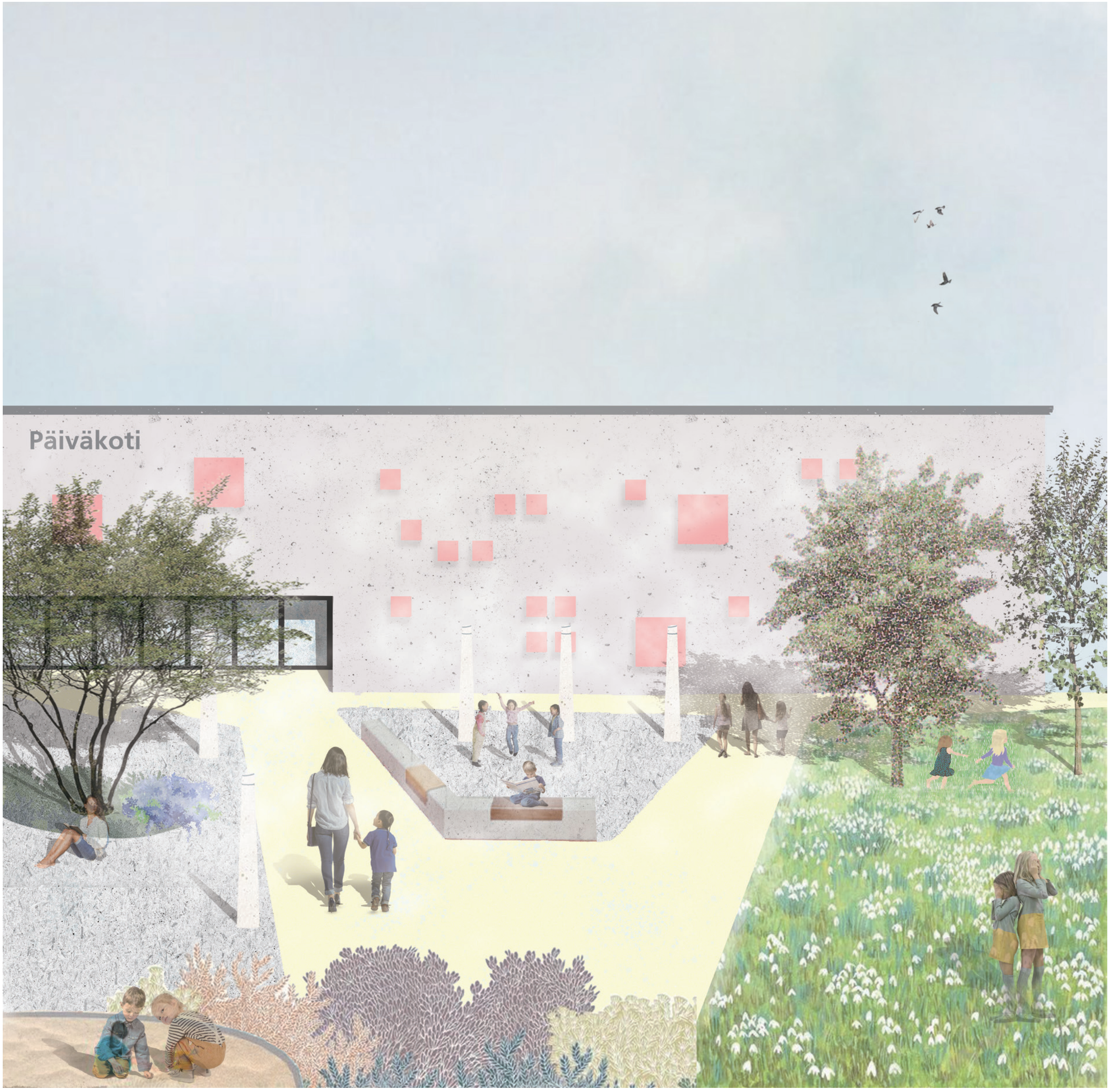
Make the design more accessible and attractive

Towards the smart city, the design and research results will be available to the public in digital offerings. Citizens and tourists can easily experience the transformations that design brings to the city through the application platform. Meanwhile, the platform will also serve as a medium to connect designers, governors, and inhabitants.

7.4 The scenario of the urban street where citizens activate the mechanism through application.

Increase awareness of climate change and carbon-neutral society

Via participating in the fight against the urban thermal environment, citizens can understand the impact of climate change on the city and life. Simultaneously, the carbon-neutral concepts in the design process will also be imperceptibly reflected in local daily lives. Furthermore, applications can also be used for educational purposes to develop children's sustainable thinkings in climate-related curriculums or workshops.



7.5 The scenario of the school where kids are playing around the cooling mechanisms.

Actions to impact locally and internationally

The proposed actions are first dealing with the increased negative impact of climate change and its effect on the people. As the devices are designed and function in a sustainable manner, the strategies reduce the impact on climate change. And the vision, that currently commonly used cooling devices could be replaced, will have a bit impact on reducing CO2 emission.

When the strategies have positively impacted Helsinki, it can be advocated in many other cities. Eventually, the whole world will participate in the action against the thermal environment, turning a sustainable urban vision into a sustainable global vision.

7.6 The scenario of the community where inhabitants collect the snow together for the usage of cooling devices.

CONCLUSIONS AND FUTURE OUTLOOK

Conclusions

In this master thesis, a systematical approach to the urban thermal environment is proposed. In order to effectively evaluate the large-scale urban thermal environment, multiple software platforms are applied and compared. Eventually, based on the supplemented SOLWEIG model, the urban thermal environment map of Helsinki is created. The simulation illustrates how different land coverings affect thermal comfort, and shadows from trees and constructions strengthen local thermal comfort significantly.

Afterwards, three different kinds of strategies are formulated to relieve thermal stress. Strategies have diverse characteristics and applicable scopes. In order to address and integrate the public, a designed web-based platform is designed to integrate all individually designed solutions into a holistic application. The application makes the design more accessible to citizens. Simultaneously, as a member of improving the urban environment, residents can cultivate an awareness of sustainable development in the involvement.

Future outlook

At present, there are several aspects of this master thesis which have the potential to be further studied.

Currently, the SOLWEIG model only supports conifer and deciduous arbors. The performance of more species of trees in heat environment simulation needs to be specified. In addition, the impact of vertical greenery in cities is not taken into consideration.

The “snow house” mechanism cools down by releasing stored snow. In Helsinki, the temperature difference between morning and evening can reach 10 degrees in summer. Another sustainable cooling device can be invented which exchange heat transferring in the evening and release cold air during the day.

How to popularize the concept of sustainable development more intuitively at the educational level can be discussed in-depth, such as conducting workshops in conjunction with the envisaged software.

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FIGURE LIST

APPENDIX

UTCI calculation

```
# -*- coding: utf-8 -*-

import math

#30 °C <= Tmrt <= 70 °C

#-50 °C <= Ta <= 50 °C

#0 <= RH <= 100

#0.5 <= va <= 17 m/s

def D_Tmrt(Tmrt, Ta):
    D_Tmrt = Tmrt - Ta
    return D_Tmrt

def Pa(Ta,RH):
    Pa = (2.7150305 * math.log(Ta + 273.15)) * (RH / 100) / 10
    return Pa

def UTCI(Ta,va,Pa,D_Tmrt):
    UTCI = f (Ta; Tmrt; va; vp)

#Omitted here because the formula is too long

   return UTCI

location = "D:/Aalto/heat/exercise/bu/experi/dsm/weather/output"

#tmrt, ta, rh, va

import pandas as pd

t1 = pd.read_csv(location+"/ta.txt",sep=" ",index_col=None,header=None)
dfta = pd.DataFrame(t1)
```

```
#dfta.columns

dfta.shape

#dfta.iloc[0,1]

#dfta.iloc[2748,2499]

t2 = pd.read_csv(location+”/va.txt”,sep=” “,index_col=None,header=None)
dfva = pd.DataFrame(t2)

t3 = pd.read_csv(location+”/tmrt.txt”,sep=” “,index_col=None,header=None)
dftmrt= pd.DataFrame(t3)

t4 = pd.read_csv(location+”/rh.txt”,sep=” “,index_col=None,header=None)
dfrh= pd.DataFrame(t4)

i=0
j=0
utcilist = dfta
while i < dfta.shape[0]:
    while j < dfta.shape[1]-1:
        Ta = dfta.iloc[i,j]
        va = dfva.iloc[i,j]
        Tmrt = dftmrt.iloc[i,j]
        RH = dfrh.iloc[i,j]
        if Ta < 0:
            Ta = 0
        if RH < 0:
            RH = 0
        if va < 0:
            va = 0
        a=D_Tmrt(Tmrt,Ta)
        b=Pa(Ta,RH)
        value=UTCI(Ta,va,b,a)
        utcilist.iloc[i,j]=value
        j = j+1
    i = i +1
    j = 0

utcilist.to_csv(location+”/utci07141700.txt”,sep=’ ‘,index=False)
```